MIM VS. CASTING:

How Does TiMIM Compare?

PRAXIS TECHNOLOGY

Advancing Titanium

There are multiple common manufacturing techniques for creating medium to large volumes of titanium alloy components. Of these, two processes, investment casting and titanium metal injection molding (TiMIM), can meet the needs of many designs.

But how do you decide whether to source investment castings or TiMIM parts? This eBook will detail both processes and highlight their advantages and disadvantages so you can choose the best one to meet your specific needs.

AN OVERVIEW OF THE
Investment Casing Process

Investment casting is a metal casting technique where molten metal is poured into a ceramic mold. Positive molds of wax or foam are dipped into a ceramic slurry for an even coating. Then the ceramic is fired, burning out the wax or foam, leaving behind the ceramic shell. This is why investment casting is sometimes called "lost wax" or "lost foam" casting. The ceramic shell is filled with molten metal, and the metal is allowed to freeze. Then the ceramic shell is broken away, leaving behind a component ready for post-processing and machining.

As complex as investment casting can be, the economics of scale do favor making large volumes of parts.

A few potential problems with investment casting are upfront tooling cost, the amount of waste generated, the contamination of components, and the difficulty with casting very small, complicated objects.

The investment casting process uses wax, some of which can be recovered. It also uses proprietary ceramic slurry, which cannot be reused. This ceramic slurry is just another potential choke point in a supply chain, and another cost in both the purchase of new ceramic as well as in the disposal of waste ceramic.

Perhaps the most significant problem with investment casting is the reduction of mechanical properties due to brittle failure that can occur with investment cast parts. The brittle failure mechanism is due to the formation of an alpha phase case that forms on the surface of the part where it contacts the ceramic mold. If not removed by chemical milling (with a particularly corrosive chemical mixture), the alpha phase can lead to sudden, brittle failure of the part. The risk of alpha case development and the need for additional corrosive chemicals puts investment casting at a disadvantage.

Investment casting must be carefully controlled to limit the defects, such as pores and cold shuts. The pores can occur anywhere trapped gases cannot escape, where molds did not fill completely, and through several other mechanisms, leading to a large distribution in pore sizes throughout the casting. Pores are especially challenging because they may not be discovered until the parts are machined, and scrapping apart after machining is even more costly. Also, the high-temperature processing can lead to warpage and shrinkage in thin-walled parts.

AN OVERVIEW OF THE

Titanium Metal Injection Molding (TiMIM) Process

Metal injection molding (MIM) is a manufacturing technique where a thermoplastic material, filled with metal powder, is melted and forced through a nozzle and into a metal mold. The thermoplastic material takes the shape of the mold, is removed, and then heat treated. The heat treatment removes the binder and sinters the metallic powder, leaving behind a dense metal component.

Titanium metal injection molding (TiMIM) is MIM using titanium alloy feedstock, such as Ti-6V-4Al, which is commonly used in the manufacture of medical devices and other high strength, low mass components for a variety of industries.

The TiMIM process produces net-shape parts, limits waste, and saves expensive titanium.

TiMIM requires precision mold design to ensure proper flow of the thermoplastic material. This initial investment represents a large portion of the cost and lead time. Once the molds have been designed and manufactured, the cost per piece for TiMIM drops significantly, becoming economical at medium to large production rates (10,000+ pieces/year).

Proper mold design allows for extremely tight tolerances on even the smallest parts. Tiny parts even smaller than 20mg can be injection molded with high dimensional stability. It is an entirely repeatable process, meeting both precision and accuracy quality control needs.

The thermal treatment removes the binder and densifies the part, creating components with low porosity (effectively 100% dense). The low porosity with virtually no interconnected pores, plus the tight dimensional tolerances made possible with TiMIM make it suitable for producing hermetic seals, and other difficult-to-produce geometries.

The Advantages *and* Use Cases

OF TiMIM

Both investment casting and TiMIM are suitable for medium- and large-scale production rates, but TiMIM offers some distinct advantages over investment casting for certain applications and use cases, particularly for parts under 50 grams. TiMIM utility extends well much smaller parts as well; some TiMIM parts weigh as little as 20mg – substantially smaller than what investment casting's capability. TiMIM generates little waste, has virtually no contamination issues, no alpha phase case, and can be used to make incredibly small or complex parts.

TiMIM is best suited for titanium parts that require one or more of the following characteristics:

- **Small and Complex**
- **Corrosion Resistance & Biocompatibility**
- **High Volume**
- **Hermeticity and Superior Finish**

Finer Microstructure

TiMIM parts have a finer, more favorable microstructure as compared to investment cast parts, regardless of whether the TiMIM is heat-treated post sintering. This is because the TiMIM grain size is linked to the tightly controlled particle size of the starting powder. Investment cast parts will be of varying grain size, based on dendritic growth and the uncontrolled cooling of the mold. Often, investment cast parts will have a coarse microstructure in the interior of the part, due to slower cooling, with grains becoming finer towards the surface of the part. At the surface, alpha case is basically unavoidable in investment cast parts the molten titanium reacts with the ceramic investment.

The larger grains and collection of alpha phase at the grain boundaries is visible on the cast titanium microstructure. Figure 1 shows a typical cast TI-6Al-4V microstructure, the alpha phase shows up as white in the micrograph. The accumulation of alpha phase at the grain boundaries is referred to as "grain boundary alpha" and is understood to negatively impact mechanical properties.

Figure 1: Typical cast titanium microstructure. The white at the grain boundaries is aggregated alpha phase, which is more brittle.

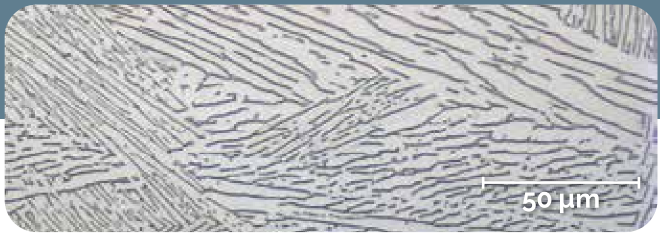


Figure 2: Investment cast sample at higher magnification.

TiMIM's microstructure does not develop from nucleation sites for grain growth, as the metal particles are not freezing from the liquid state. Instead of a dendritic, needle-like structure, the metal particles in the feedstock become the initial grains in the TiMIM microstructure. Ultimately, this means TiMIM has finer, more equiaxed grains.

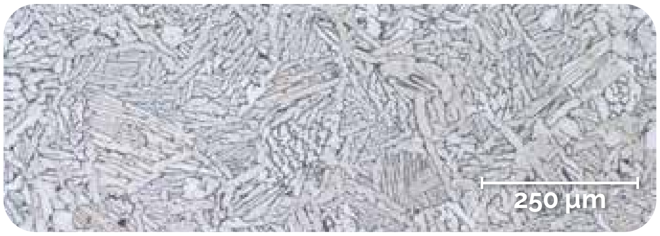


Figure 3: TiMIM sample. Virtually no grain boundary alpha is present, and the grains are finer and more equiaxed than those created during investment casting.

Figure 4: A higher resolution image of the TiMIM sample.

To further improve the microstructure and thus improve the mechanical properties there are two main options. TiMIM product can be hot isostatically pressed (HIP) to eliminate porosity, which will improve surface finish and provide modest improvements in static tensile properties. Further it can be heat treated, such as through TIRxTM, Praxis' own post-treatment process. TiRx greatly improves static and dynamic properties of the finished product by refining the microstructure.

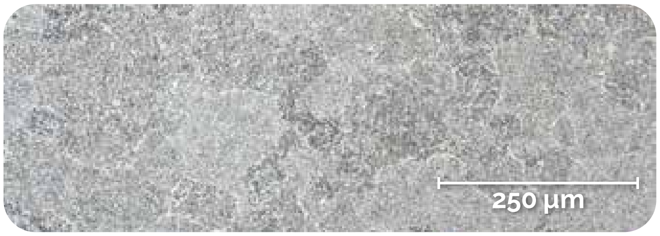


Figure 5: TiMIM + TIRx. Very little grain boundary alpha, and finer, more equiaxed grains.

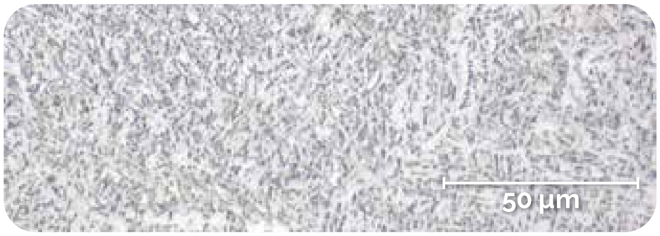


Figure 6: A higher resolution image of a sample manufactured through TiMIM + TiIRx.

Better Mechanical Properties

Linked directly to microstructure, the mechanical properties of TiMIM processing are more favorable than those of investment casting in most cases. TiMIM parts are more ductile and tougher, meaning they are less likely to be damaged by impact and will deform plastically before breaking. The smaller grain sizes and lack of alpha phase aggregation in TiMIM parts is a major contributor to this property.

TiMIM parts are also stronger, as shown in the table below. The fine, equiaxed grain structure leads to a stronger alloy.

Favorable Heat Treatment

The positive effects of TiMIM are amplified after a proper heat treatment. Heat treating TiMIM parts improves tensile strength and other static and dynamic properties. While cast Ti-6AL-4V is typically annealed to reduce residual stress, the cast alloy does not otherwise respond well to heat treatment to increase tensile properties or elongation.

Cast parts are often annealed, but this is only to remove residual stresses that developed during cooling. The annealing process does not refine the grain structure enough to affect its tensile strength or ductility, but it does reduce the variability in ductility between samples. Because TiMIM is not poured from a melt, residual stress development is limited as a function of the process, and little annealing is required.

The table below shows a comparison of material properties between cast and MIM materials. From the chart, the MIM materials have better yield strength (YS) and ultimate tensile strength (UTS). They are also more ductile, as shown by the higher percent elongation and reduction of area metrics.

	SPECIFICATION		ACTUAL (Typical)	
ELEMENT/PROPERTY	**ASTM B367** **Ti-6Al-aV** *Cast*	**ASTM F2885** **Ti-6Al-4V** *MIM*	**Praxis MIM** **Ti-6Al-4V** *Typical Values*	**Praxis MIM** **Ti-6Ai-4V** *Heat Treated*
MECHANICAL PERFORMANCE				
UTS MPA (ksi)	860 (125)	900 (130)	965 (144)	1070 (155)
YS MPA (ksi)	758 (115)	830 (120)	860 (128)	965 (140)
ELONGATION %	8%	10%	18%	16%
REDUCTION OF AREA	14%	15%	40%	40%

The end result is TiMIM parts have better overall mechanical properties, with higher ductility, less chance of brittle failure. They also have better dynamic properties.

Less Material & Energy Waste

With investment casting, lost foam or lost wax components are connected to a sprue and a large tree that feeds liquid metal into each component. After the melt has frozen, the sprue and tree are cut away. While much of this material can be recycled into the next melt, the energy cost for melting metal in not recoverable. Besides the additional energy costs, use of ceramic for the investment creates an additional waste stream with not easy recovery options for the investment caster.

TiMIM, in contrast, often produces net shape parts, minimizing the need for post-processing. It also does not require as much heat energy for thermal treatment as investment casting requires to melt the metal. Further, sprues and runners are easily recovered and reused. All of this translates to lower energy costs with TiMIM.

Less Risk of Contamination

In terms of contamination, investment castings are more likely to be contaminated. The ceramic shell, residues from the wax burnout, slag, oxidation, and other sources can lead to contaminated final products. This is a particular concern for implantable parts, which can be rejected by the body if they contain non-biocompatible materials.

The pouring process can also introduce pores from turbulence or from entrained gasses trying to escape the ceramic investment. Furthermore, some parts may suffer from cold shuts, where molten metal approaching from different sides may touch, but not fully bond. This reduces the strength of the part significantly.

Better Quality Control

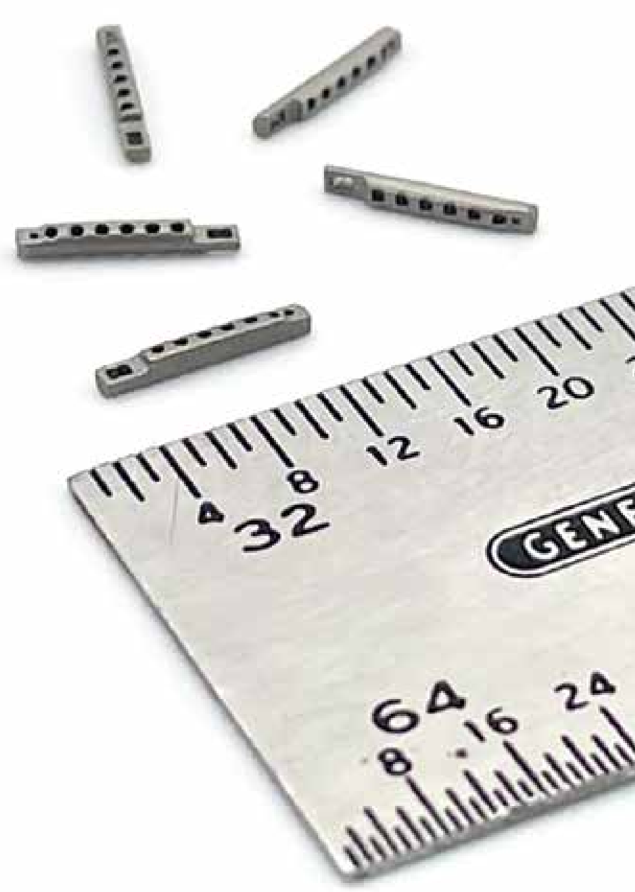
Because the only way to make investment castings economically is to attach many parts to a sprue and a tree, the pressure gradient that drives the molten metal varies based on each part's location on the tree. This means parts at the top of the tree and parts at the bottom of the tree will not cast with the same forces. For complex parts with thin sections, ribs, and other such geometries, variability based on tree location can translate to more rejected parts during quality control.

TiMIM ensures that each mold is filled using the exact same amount of pressure, meaning the first part and the last part will be identical over thousands of parts. This consistency leads to a lower scrap rate and higher customer satisfaction in the long run, as compared to investment casting. Overall, TiMIM offers significant advantages at a competitive price.

Size Limitations

TiMIM excels at making large numbers of tiny parts. If the part is under 20 grams, TiMIM has the greatest advantage over investment casting, as it is incredibly difficult to cast such small parts. While there is some overlap between TiMIM and investment casting for parts under 50 grams, TiMIM is much more scalable and often is more economical. Above 50 grams, and some of the limitations of investment casting are reduced.

In general, TiMIM is best for making tiny, precision parts at high volumes.



Summary

Both technologies have their advantages and disadvantages when manufacturing titanium components. Investment casting can provide for larger parts, and the lower upfront tooling cost makes smaller production quantities more economically viable. MIM excels at smaller, more complex parts and generally requires higher production volumes to offset the tooling cost. MIM can also provide higher static and dynamic properties, and a more consistent microstructure. Heat treatments are also available to greatly improve static and dynamic performance.

The table below compares both technologies for several manufacturing considerations:

	TITANIUM INVESTMENT CASTING	TITANIUM MIM
THIN SECTIONS	No	Yes
SMALL PARTS (>20 gram)	No	Yes
LOW VOLUME RUNS	Yes	Maybe
TOOLING COST	Maybe	No
SURFACE FINISH	Maybe	Yes
LARGE PARTS	Yes	No
STATIC PROPERTIES	Maybe	Yes
DYNAMIC PROPERTIES	No	Yes

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The Praxis Advantage

Praxis has specialized in TiMIM processing for over 15 years, manufacturing parts for many industries, including medical, defense, and consumer electronics.

Interested in learning more about how your next high volume production run can benefit from TiMIM? Contact our experts today and allow us to guide you through the process.

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