

TITANIUM RAMMED GRAPHITE CASTINGS

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Titanium rammed graphite casting is a technology in which wood, metal, or plastic molds are lined with graphite to prevent molten titanium from reacting with mold materials. Graphite powder is mixed with water, pitch syrup, and starch, and pneumatically tamped and rammed around the pattern. Molds are air dried for approximately 24 hours to achieve a green (uncured) strength before they are baked at a low temperature to prevent steam generation and cracking during the firing step. Molds are fired in excess of 1500°F (815°C) to develop the final bonds and to burn off binders, resulting in a hard and rigid final product.

Similar to conventional sand castings, rammed graphite molds consist of the standard cope and drag patterns, with and without cores. Many parts can be cast in the same patterns originally constructed for the casting of other metals (Fig. 1). Standard loose or match-plate patterns made of either wood or metal are also suitable for titanium rammed graphite castings, and most patterns for

ferrous and nickel-based alloys conform dimensionally (Fig. 2). Generally, pattern equipment designed for sand casting processes can also be utilized, with modifications to gating and riser systems.

Molds must be carefully designed to allow the proper flow of molten material and to ensure that shrinkage takes place in the gates and risers rather than in the finished casting. The maximum size of a titanium pour is approximately 1800 pounds, yielding a final part that weighs about 1300 pounds; however, larger castings have been produced by utilizing multiple pours and molds. The maximum single pour has been 50 inches in diameter by 72 inches in height. Walls as thin as 0.1875 inches have been produced via the rammed graphite method.

Melting and casting

To make the castings, consumable electrodes are melted in a water-cooled copper crucible in a vacuum arc furnace (Fig. 3). Electrodes are either forged billet, consolidated revert, or a combination of the two.

The mold assembly is placed on a table in the bottom of the furnace where the titanium can be centrifugally or statically cast, depending on geometry and specifications. The furnace is sealed, a vacuum is drawn, and an arc is struck on revert material placed in the crucible. When the proper amount of material has melted, the crucible is tipped and the molten material is poured into the mold. The mold assembly is left in the furnace under vacuum until the metal has cooled to the proper temperature.

After the mold assembly is taken out of the fur-

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Fig. 2 — Wood patterns can be used to produce rammed graphite molds.

Fig. 1 — This pump housing was cast via the rammed graphite process.

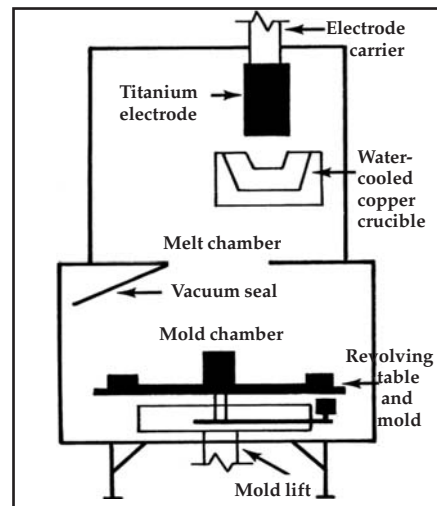


Fig. 3 — This schematic shows the parts of a vacuum arc furnace.

Table 1 — Chemical compositions of various grades of titanium, in max. wt%.

ASTM Designation	Ti (min)	C	H	O	N	Fe	Others
Grade 2	98.885	0.10	0.015	0.25	0.03	0.30	0.30
Grade 3	98.885	0.10	0.015	0.35	0.05	0.30	0.30
Grade 5	Remainder	0.10	0.015	0.20	0.05	0.30	6.75 Al, 4.50 V
Grade 7	99.005	0.10	0.015	0.25	0.03	0.30	0.12-0.25 Pd
Grade 12	Remainder	0.10	0.015	0.25	0.03	0.30	0.2-0.4 Mo, 0.6-0.9 Ni
Grade 38	Remainder	0.00	0.00	0.25	0.00	1.50	4 Al, 2.5 V

Titanium, 2nd Edition, is a comprehensive summary of the current state of the art of titanium. To learn more, visit www.asminternational.org, and click on the "ASM Store" button. It is listed under "New Releases."

nance, the graphite is removed by traditional "knockout" methods, and the gates and risers are cut off by an oxyacetylene torch. The metal surfaces in contact with the mold are contaminated with carbon, which must be removed by blasting and/or pickling. The pickling solution is generally a mixed acid solution of 15 to 30% nitric acid, 3 to 5% hydrofluoric acid, and water.

Once the "knockout" has been completed, the casting goes through nondestructive testing and inspection to determine any necessary finishing processes. Depending on the product and customer specification, castings may be inspected by visual, liquid penetrant, and/or radiography methods; they may be checked for dimensional precision as well.

Eliminating defects

After casting, the parts are hot isostatically pressed (HIP'ed) to eliminate any porosity. Castings are placed in the HIP chamber, the temperature is raised to 1500°F (815°C), and a pressure of about 16,000 psi (110 MPa) is applied by an inert gas such as argon. The voids are "healed" by the pressure of the gas on the material.

After the HIP process, penetrant inspection is usually performed. Defects found through penetrant inspection include porosity and voids on the surface. If any are found, the casting is repaired by welding.

Radiographs can also detect any possible graphite inclusions that were not healed during the HIP process. However, such inclusions are very rare. The combination of HIP and penetrant inspection has greatly reduced the need for radiography, thus reducing the cost and lead time for a cast part.

Advantages of rammed graphite castings

Titanium rammed graphite castings have become a viable alternative to the conventional fabrication methods of titanium plates and components. The labor-intensive fabrication methods that previously relied on cutting, machining, and fitting plates to be welded are being replaced by simpler near-net-shape castings. Titanium foundries have successfully replaced welded fabrications on many occasions. This provides engineers with less costly parts that have a lower chance for error because fewer welds are needed on a casting than on cut and fitted plates.

The fact that a rammed graphite casting is repeatable is also very beneficial to contractors and end users. The upfront cost of patterns is lower and more affordable than the tooling required for investment castings. The pattern is dimensionally correct each and every time, and is based on the end user requirements.

The casting maintains the dimensions designed into the pattern, so the larger envelopes that often accompany forgings, billet, and plate stock are eliminated. A near net shape can eliminate extra hours of machining and milling, as well as solve the problem of handling the extra chips and turnings that are generated by machining.

Rammed graphite castings often provide the advantage of being more readily available than fabricated or machined components. The current titanium market is experiencing unprecedented lead times for mill products such as plate, billet, and forgings. It is not unusual to wait 30 weeks for the arrival of the raw materials before any fabricating or machining is possible. Rammed graphite casting lead times can be significantly shorter because the melt stock raw materials are more readily available than mill products, and processing lead times for rammed graphite castings are much shorter than those for plate, billet, and forgings. Generally, a prototype casting can be available within a 15- to 20-week lead time, which also includes the production of the patterns. More complex parts may require longer lead times.

Military alloys

The lightweight and durable characteristics associated with titanium have caused designers to consider titanium rammed graphite castings for a growing number of applications on military vehicles. Suspension system components have been reviewed and prototype castings have been produced for a number of companies, with very good

Table 2— Minimum strength specifications for cast and wrought titanium

Titanium grade	Tensile strength, ksi (MPa)	Yield strength 0.2% offset, ksi (MPa)
Cast Grade 2	50 (345)	40 (275)
Wrought Grade 2	50 (345)	40 (275)
Cast Grade 3	65 (450)	55 (380)
Wrought Grade 3	65 (450)	55 (380)
Cast Grade 5	130 (895)	120 (825)
Wrought Grade 5	130 (895)	120 (828)
Cast Grade 38	130 (895)	115 (794)
Wrought Grade 38	130 (895)	115 (794)

results. The combination of low density, good fracture toughness, and the ability to produce near net shapes make it very attractive. Idler wheels, idler arms, sprocket carriers, and other components for suspension systems are ideal candidates for titanium rammed graphite castings. Table 1 shows the chemical compositions of the titanium alloys in rammed graphite castings.

- **Grades 2 and 3** are commercially pure and are the most requested grades for chemical processing applications.

- **Grades 7 and 12** are often chosen for applications in which corrosion is more severe.

- **Grade 5 (Ti-6Al-4V)** is the preferred alloy for applications in which strength and ballistic resistance properties are an issue. Historically, this has been the alloy of choice for military applications.

- **Grade 38 (Ti-4Al-2.5V)** has recently been accepted by ASTM. It is being considered for military applications because it has proven to be very castable and much easier to pour than Grade 5. Although it is a new alloy, Grade 38 has been selected for a number of military cast parts, and in some cases has replaced Grade 5. The advantage in specifying Grade 38 is cost. While the properties of Grade 5 and Grade 38 are similar, Grade 38 has a slight pricing advantage over Grade 5 because the raw material cost is lower, and Grade 38 has better corrosion properties.

To date, Grade 38 titanium has been selected for suspension system applications, cast hatch

covers, and other components for fighting vehicles. Ballistic tests on cast Grade 38 materials are currently underway to determine its level of threat resistance capabilities.

Corrosive environments

The majority of titanium alloys (wrought or cast) are very resistant to corrosive attack and virtually immune to many oxidizing and reducing environments. This is due primarily to a tenacious oxide film that is formed when titanium is exposed to the atmosphere. The oxide film acts as a barrier to the surrounding corrosive environment and thereby protects the alloy from further oxidation and corrosion. By adding small amounts of palladium or molybdenum and nickel, corrosion resistance can be improved further.

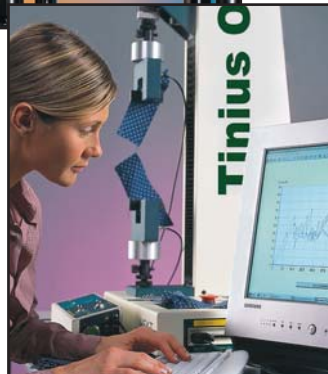
Strength and structural integrity

Unlike aluminum and steel alloys, which tend to lose structural integrity and strength when cast, titanium tends to maintain structural integrity and strength that is comparable to wrought titanium products. Table 2 illustrates this point by comparing tensile and yield minimums for wrought and cast titanium alloys in chemical processing and defense applications. ◆

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