Making Lighter Aircraft Engines with Titanium Aluminide Blades

The current state of net shape casting

Titanium aluminide is a new material that will lead to much lighter aircraft engines, and thus lighter aircraft. Net shape precision casting is the latest development in the ancient technique of casting, and is used to mass-produce hundreds of turbine blades accurately and at low cost. By also applying a revolutionary melting technology, the mass production of titanium aluminide blades becomes possible.

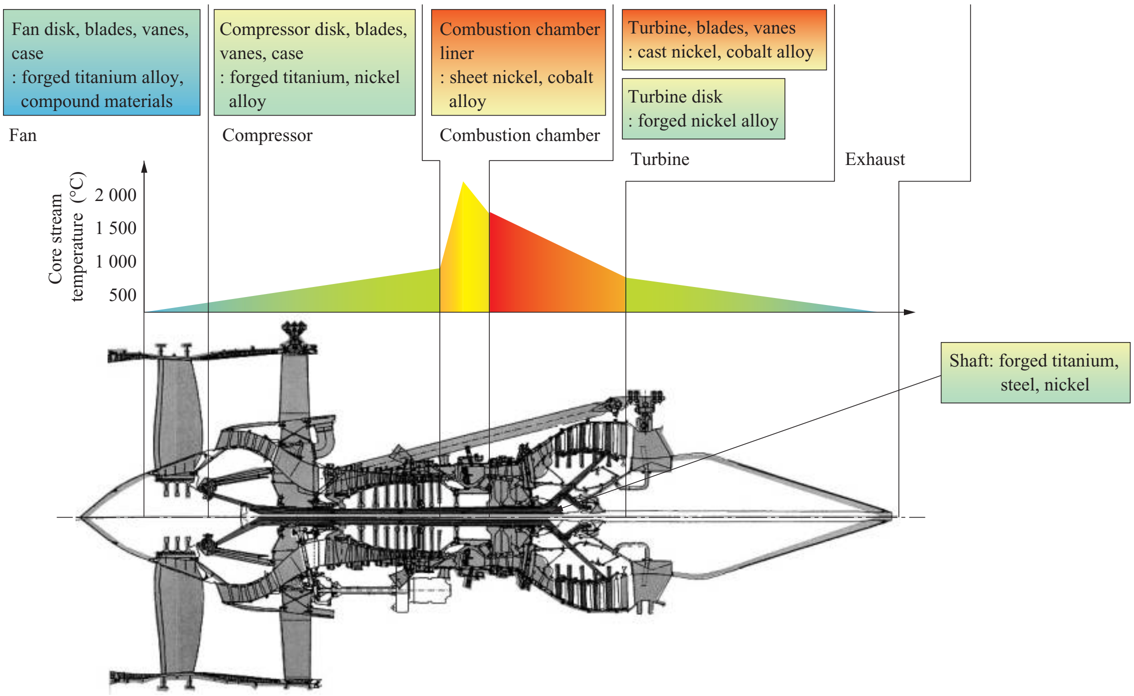
TAKEKAWA Mitsuhiro
KURASHIGE Masashi
Materials Technology Department
Research & Engineering Division,
Aero-Engine & Space Operations,
IHI Corporation

Titanium aluminide turbine blade

Lighter, stronger, higher temperature

In order to reduce the burden on the global environment, environmental standards are being raised every year in a variety of fields. There is also demand for excellent environmental performance from aircraft, ranging from improved fuel efficiency to reduced noise. In particular, as the price of fuel continues to rise in recent years, there is an even greater need for fuel efficiency improvements, and this trend is expected to continue in the future.

The engine plays a major role in improving the fuel efficiency of an airplane, for the following two reasons. ① Obviously, fuel efficiency improves with lighter aircraft, and manufacturers are finding ingenious ways to shave off grams from the total weight. Lighter engines not only have the merit of being lighter themselves, but also lead to lighter engine support structures. As a result, lighter engines are extremely beneficial for reducing the total aircraft weight. ② Improvements in the efficiency of the engine consuming the fuel lead directly to improvements in the fuel efficiency itself. In this respect, thermodynamics tells us that the higher the combustion temperature, the better.



Schematic of jet engine

The basic components of a jet engine are a fan, a compressor, a combustion chamber, and a turbine, and the inside of the combustion chamber where the temperature is hottest must be able to withstand temperatures close to 2 000°C. As engines have become hotter, the material used for the turbine following the combustion chamber has transitioned from heat-resistant steel primarily containing iron to heat-resistant alloys primarily containing nickel or cobalt. In addition, the practical implementation of new materials such as Ceramic Matrix Composites (CMCs) is advancing.

Currently, IHI is pursuing research that aims to substitute the nickel alloy used in the low-pressure part of the turbine with titanium aluminide, which boasts superior properties.

Precision casting yields complex shapes

Heat-resistant alloys such as nickel alloys have the merit of excellent specific strength (strength divided by density) in high-temperature regions, but are difficult to process. A single engine requires several hundred turbine blades, and these complexly shaped turbine blades must be mass-produced with high dimensional precision. To accomplish this task, a method called precision casting is used.

Property		Nickel alloy (typical)	Titanium aluminide alloy
Specific weight	(g/cm^3)	Approx. 8.2	Approx. 4.2
Specific strength at high temperature	(strength/density)	High	Very high
Castability		Good	Poor
Product fabrication cost		Inexpensive	Expensive

Comparison of nickel alloy and titanium aluminide alloy

Casting is one of the oldest metalworking technologies. With casting, molten metal is poured into a mold where it solidifies, yielding the required shape. Precision casting is also a technology that has been in use since ancient times, and it has been used to fabricate objects such as Buddhist statues, works of art, and ornaments. Today, precision casting is also being used for fashion accessories as well as golf club heads and dental therapy.

Although there are several types of precision casting, this article will describe the overall process of the lost-wax casting method being used to fabricate turbine blades.

Casting involves using a mold that serves as the “original” of the product, but whereas in typical casting a wooden mold with the same shape as the product is repeatedly used, in lost-wax casting, a wax mold is used instead of a wooden mold. First, a metal mold is used to create wax molds (wax patterns), as many as the number of turbine blades. The completed wax molds (wax clusters) are grouped around a central sprue that pours molten metal. Processing multiple wax molds at the same time increases productivity.

By alternately layering slurry (a liquid mixture of ceramic powder dissolved in a binder) and stucco (sand) around the assembled wax molds, a casting mold is formed on the outside. Next, the wax molds on the inside are melted and discharged with an autoclave. This is why this casting method is called lost-wax casting. Afterwards, the casting mold is fired in order to obtain sufficient strength.

Molten metal is poured into the hollow cavity created by the lost wax. After solidification, the individual parts are cut away, finished, and subjected to various tests before being considered completed products.

Besides turbine blades, this kind of precision casting is also being used to fabricate consumer goods such as impellers for automobile turbochargers, golf club heads, and ornamental objects.

The challenges of working with titanium aluminide

Titanium aluminide blades, which are still being developed, are intended for application as blades in the low-pressure turbine part of an engine. The reason for this is that lighter turbine blades also lead to a lighter disk where the blades attach, which yields a significant reduction in weight. Table 1 compares the material properties of a conventional nickel alloy and a titanium aluminide alloy. Titanium aluminide has a specific weight that is approximately half that of nickel alloy, and a sufficient specific strength in high-temperature regions, but its poor castability makes mass production difficult, and fabrication costs are also high. However, if mass production using precision casting similar to that for nickel alloy production could be achieved, it would be possible to fabricate titanium aluminide blades easily and inexpensively.

In order to achieve this goal, the establishment of an efficient titanium aluminide blade fabrication process is indispensable. IHI is currently engaged in the development of a titanium aluminide casting process that uses a precision casting process similar to conventional nickel alloy.

There are several challenges in conducting precision casting with titanium aluminide. The first is the high reactivity of titanium aluminide. Casting involves pouring molten metal into a casting mold, but with conventional techniques, the titanium aluminide reacts with the crucible used for melting and the casting mold, and the substances generated by such reactions are mixed in as impurities. Also, since the portions that reacted with the casting mold differ from the designated alloy in their composition, after casting these portions must be removed by some method, such as machining (cutting) or chemical removal. As discussed later, the question of how to reduce the number of machining steps after casting is an issue that must be faced in order to achieve a practical titanium aluminide casting process.

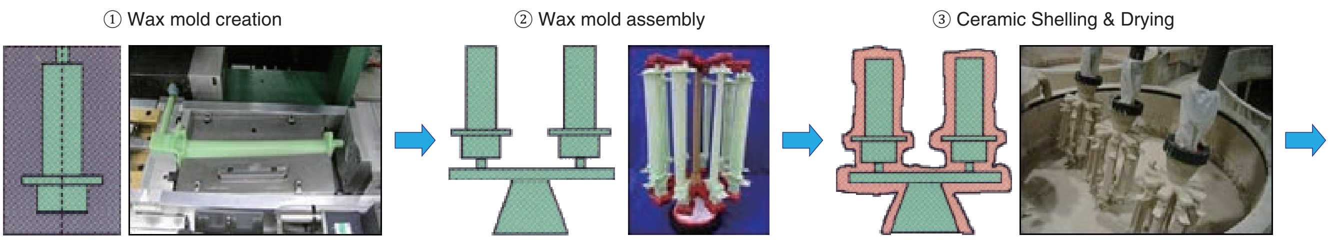
The high melting point of titanium aluminide (over 1 500°C) also makes precision casting difficult. Metallic materials are melted in a vacuum in order to avoid reactions with oxygen. For this reason, if melting takes too long, there is a risk of the aluminum evaporating, which would cause a change in the composition. The material composition of turbine blades is required to strictly adhere to prescribed standards, so changes in the composition during melting must be avoided. For this reason, a high-output heating system able to rapidly heat material up to a high melting point becomes necessary.

Molten titanium aluminide has poor fluidity, another factor that makes the precision casting of titanium aluminide difficult. In the field of casting, fluidity is a term referring to the property of a molten metal's ability to flow evenly into every corner of a casting mold. Turbine blades are only several millimeters thick in some areas, so the product shape cannot be formed if fluidity is poor. For this reason, titanium aluminide blades previously developed by IHI were fabricated by first making a “fat casting,” which has more machine stock and is larger than the final shape, and then cutting away unwanted portions by machining to reach the final shape. One goal of the current casting process development is to cast a “net shape” that is close to the final shape with casting alone.

Conventionally, casting with materials having poor fluidity has involved the use of technologies such as centrifugal casting that utilizes centrifugal force, and vacuum casting, in which molten stock is drawn into the mold cavity. However, with the new casting process we are aiming to utilize the current nickel alloy casting process to the maximum extent possible. Finding ways to minimize investments in new equipment and reduce fabrication costs is a major issue in process development.

Reaching for the skies of 2020

As discussed above, there are various challenges in casting titanium aluminide with precision to yield a net shape. The IHI Group has a history of achievement in the mass production of nickel alloy turbine blades using net shape casting technology. In addition, IHI has accumulated a wealth of knowledge about casting titanium alloy parts. However, developing a precision casting process requires knowledge and know-how in not just metallurgy and



material science, but also diverse fields such as electricity, chemistry, and analysis. By combining technical expertise from each field in the IHI Group, we have been able to outline solutions for the major challenges of the new process development.

For the melting of titanium aluminide, applied electromagnetic field technology and analysis technology were utilized to improve the induction melting technique used to melt titanium alloys and other high-melting-point alloys. In addition, rapid heating has been achieved using melting furnace control technology.

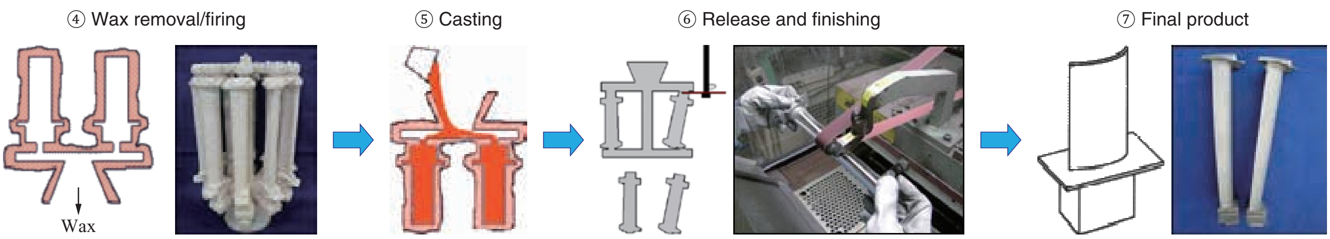
With respect to the fluidity of titanium aluminide, the properties of molten metals at high temperature are still not well understood, and measuring their physical properties is difficult. In this development project, casting analysis technology was utilized to the maximum extent in conjunction with IHI’s abundant knowledge, experience, and know-how regarding nickel-cast blades and the casting of titanium alloy parts.

Solutions to each issue are coming within reach, and currently, development is advancing into the final stage towards the goal of practical implementation as a fabrication process.

Typically, it is said that developing an aircraft engine takes six to seven years. At the earliest, titanium aluminide blades fabricated using the newly developed precision casting process could be adopted into the next generation of jet engines whose development is currently underway.

We will continue developing this process while aiming for practical application, in the hope that jet aircraft equipped with titanium aluminide blades fabricated with net shape casting technology will be flying through Japan's skies when the Olympics are held in Tokyo in 2020.

Inquiries:
Research & Engineering Division,
Aero-Engine & Space Operations,
IHI Corporation
Phone: +81-42-568-7859
Website: www.ihi.co.jp/en/



Precision casting process