Fig. 1. Turbine blades, a casting test grid and turbocharger wheels made of TiAl with a one Euro coin for comparison of the sizes

Titanium – Material for Aerospace and its Processing

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Due to its physical and chemical characteristics and its biocompatibility, titanium, its alloys and intermetallic compounds are popular materials in aerospace, automotive, chemical engineering and medical-technology applications.

In comparison with titanium, the intermetallic compound titanium-aluminium (TiAl) has a lower specific weight. This compound is utilized in the aircraft industry as a material for engine components (e.g., turbo-superchargers, pistons, turbine blades and valves) as well as the optical and medical-technology industries. Due to the low specific weight of the material, the use of TiAl in turbine blades and turbo-chargers (Fig. 1) reduces the weight, which results in a fuel-savings cost reduction.

Although the demand for complex titanium parts is increasing, the cost of manufacturing these parts continues to be high. Manufacturing components made with titanium is more work with higher associated cost than conventional metals/alloys. Mechanical machining such as milling must be done slowly and carefully with high tool wear.

Aerospace and Medical Applications

For the special use in aerospace and medical technology, Linn High Therm, in cooperation with ACCESS e.V., an Institute of RWTH Aachen, succeeded in developing an improved precision-casting system for titanium and titanium alloys.

It is possible to manufacture net-shaped components with the highest accuracy grade of 0.1 mm and very good surface quality. It is possible to manufacture intricate-shaped components with undercuttings and sophisticated designs that are either difficult or impossible to produce by mechanical means.

The cast parts are nearly in their final shape. Therefore, very extensive post-cast processing can be reduced to a minimum. The difficult processing of the very thin-walled areas of turbocharger wheels and turbine blades can be eliminated completely (Fig. 1). Hence, the design of these areas is not constrained by production-orientated restrictions. It can almost exclusively comply with the fluidic conditions inside the mold.

The post processing generally consists only of the separation of the cast part with a cutting disc and finishing of the gate locations. Further post-processing steps such as polishing and sandblasting can also follow.

Precision Induction Centrifugal Casting

Precision fine casting with induction centrifugal casting units is a pressure-casting procedure that highly outmatches the conventional gravity precision casting in relation to material density and shape filling. Compared to the cold-wall crucible process, it is very cost-effective and energy-efficient.

To address the extreme reactivity of titanium, the previously common melting methods – electric arc melting and melting in a cold-wall crucible – are costly. The melting of material in a ceramic crucible by means of inductive heating with high or medium frequency saves time and energy and requires minimum plant space. Comparatively, these systems are low cost, easy to operate and have precise temperature control.

Fig. 2. Titanium casting parts for medical applications

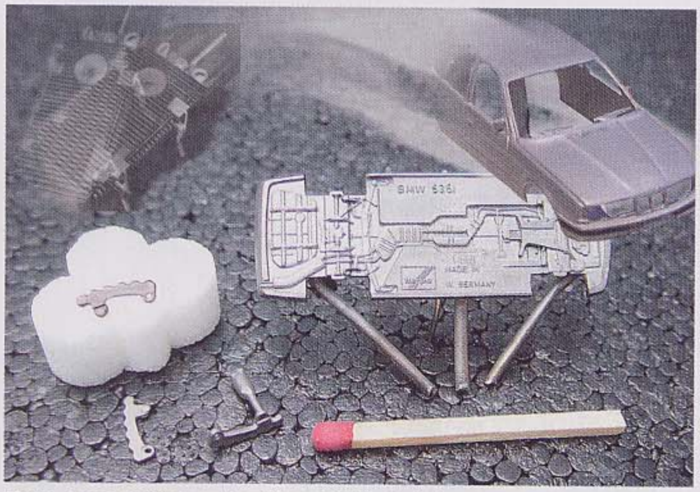

Fig. 3. Small casting parts with sophisticated shapes

Fig. 4. Induction centrifugal casting unit, Supercast, with medium-frequency inverter

The production of vacuum and the flushing of the casting chamber with protective gas extend the application possibilities of induction centrifugal casting units. Relative to titanium and titanium compounds, the melting and casting process takes place under vacuum or inert-gas atmosphere in order to avoid gas reactions with the melt.

With the combined vacuum-induction-centrifugal compact casting systems, it is possible to economically obtain precision fine casting under vacuum and/or protective gas. If the required ceramic casting molds are available, changing production to another casting is quick and economical. It is also economical for short production runs.

Equipment and Process Variability

In addition to titanium, the advantages experienced using precision fine casting with induction centrifugal casting units can also be seen on a wide range of materials such as Co/Cr alloys, steels, stainless steels, copper, magnesium, etc.

Induction centrifugal casting units are produced in sizes from a small table unit for a maximum casting weight of 40 grams to the Supercast (Fig. 4) with a maximum casting weight of 3.5 kg, depending on metal/alloy. The size of the cast components is just millimeters (Fig. 3) to a length of 300 mm (Fig. 1).

With these systems, casting into a metal mold as well as the precision fine casting lost-wax technique into ceramic molds is possible. The dewaxing furnaces, preheating furnaces and post-processing furnaces, which are needed for the lost-wax technique, are also part of the delivery scope. As a long-term partner of Linn High Therm, ACCESS e.V. is in the position to optimize the casting processes by computer simulation and actual casting tests.

For the production of titanium and γ-TiAl components, an automatic casting line with S7 control is offered in which the necessary preheating furnaces, centrifugal casting units and heat-treatment furnaces are combined in one functional unit (Fig. 5).

The centrifugal casting units can also be used to prepare samples for spectroscopy. The advantages are good reproducibility, small material losses and high working speed compared to conventional processes, especially for the production of calibration standards.

Melting Crucible

The casting material is melted by induction in the ceramic melting crucible. Due to the hot melt, a high mechanical- and chemical-strength crucible material is demanded, and a good thermal shock resistance is required.

Some casting materials (e.g., stainless steels, superalloys or titanium) are very reactive when molten, and even higher standards are demanded from the melting crucibles concerning chemical resistance. Furthermore, it must be ensured that no undesired materials are released to the melt from the crucible material.

In order to achieve high process stability, an exact adjustment of crucible material, crucible shape and casting material is required. With the help of 3D-simulation programs (Fig. 6), casting processes have been simulated with a large variety of conditions. A series of melting crucibles with optimal crucible shapes have been developed for a large range of applications. For this reason, a custom-made melting-crucible design is typically not necessary.

Vacuum and Inert Gas

To eliminate undesired reactions of the casting material and to benefit the complete filling of the casting mold, a vacuum can be generated for extraction of remaining oxygen, and additional flushing with inert gas can be performed. Therefore, a vacuum system and an inert-gas flushing unit is integrated into Linn casting systems.

The axis of the casting arm is designed as a hollow shaft. It is connected over a vacuum-tight rotary transmission feed with the pump system (Fig. 7). Inert gas (e.g., argon, nitrogen, forming gas) is used to flush the chamber.

For the casting of titanium and its alloys, the vacuum system has been improved, and the pump program was adjusted to the unique requirement of casting titanium. Typically, the vacuum system consists of an 800-m^3/hour Roots-type pump and a corresponding backing pump. This pumping station allows short evacuation times and guarantees the required vacuum during melting and casting. A working vacuum of 5×10^{-2} mbar can be reached within 20 seconds, and maximum final chamber vacuum of 10^{-3} mbar is possible.

Induction Melting

The principle of induction heating is comparable with a transformer. The ceramic-embedded, water-cooled induction coil (primary winding) induces eddy currents in the casting material (secondary winding) that are directly transduced into heat by Ohmic losses. In addition to the heating of the casting material, the eddy currents coincidentally generate a stirring action that guarantees highest homogeneity and reproducible casting results for all alloys and metallic compounds.

A 20-30 kW, 10-20 kHz medium-frequency generator enables short heating rates. Melt temperatures can be reached quickly for titanium and titanium alloy casting.

The temperature measurement is performed by a noncontact pyrometer that measures the temperature of the melt through the observation window of the casting arm and transfers it to the S7 control. To facilitate monitoring, a picture of the pyrometer is shown on the monitor (Fig. 8).

Centrifugal Casting Process

The powerful, speed-controlled special motor rotates the casting arms and provides an exact acceleration of the material, achieving specified casting parameters during the actual casting stage. All parameters of all process steps are automatically controlled by program controllers.

For titanium casting, the angular acceleration of the casting arm has been increased. Due to titanium's small specific weight and high melting point as well as solidification speed – in contrast to other metals – it has to be pressed into the mold with higher forces to fill it out completely during casting.

Depending on the geometry of the part, the acceleration and the final rotation speed of the casting arm can be adjusted steplessly using a servo motor with frequency converter (e.g., for Supercast from 1-15 seconds and 0-300 rpm).

Fig. 5. Automatic casting line for titanium and TiAl components

The Supercast series is equipped with a modern Siemens S7 PLC with touch panel and casting-recipe program. The cycle can be completed either in manual or in automatic mode so that the vacuum pumps, protective gas flushing, casting and centrifugation can be independently performed by the system. This guarantees a safe, reproducible process flow, and the casting parameters can be adhered to 100%.

Heat Treatment

Some materials (e.g., titanium alloys for aerospace applications) require a heat treatment directly after the casting. The cast parts are inserted into a heat-treatment furnace (Fig. 9) immediately after casting where they achieve pre-adjusted temperatures, holding times and defined cooldown times. The furnace can be a continuous belt furnace or a batch chamber furnace.

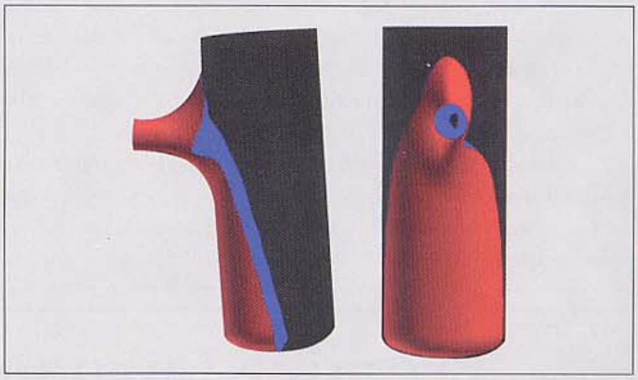

Fig. 6. 3D simulation of the melt flow process during titanium centrifugal casting

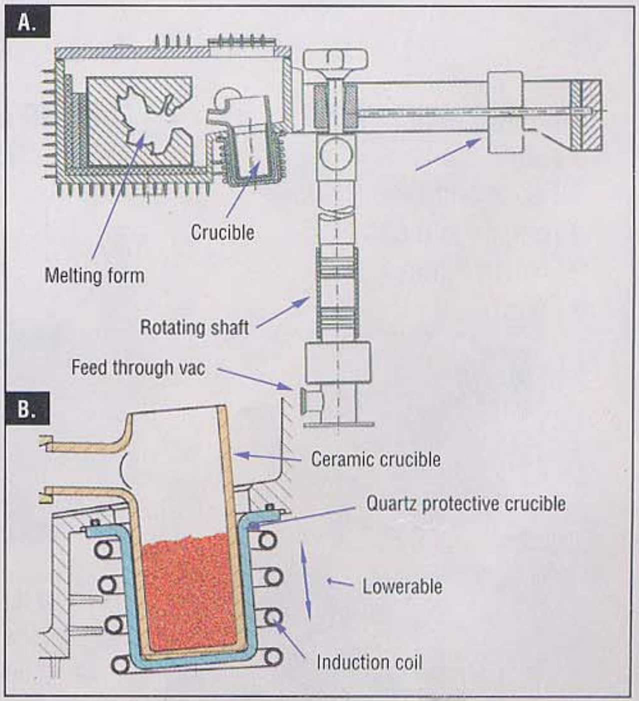

Fig. 7. A. Casting arm with shaft and rotary transmission lead through, B. Melting crucible with induction coil

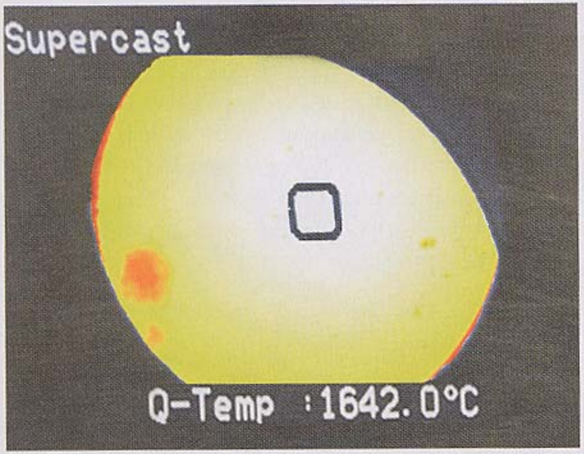

Fig. 8. Video frame of pyrometer, TiAl melt shortly before cast

Fig. 9. Cast mold inserted into a belt heat-treat furnace

Conclusion

Induction centrifugal casting systems allow the economic but process-stable casting of near-net-shaped metal or alloy components. Especially interesting are casting systems for the processing of material with stringent requirements (e.g., titanium and intermetallic compounds like γ-TiAl or FeAl).

Due to their wide product range, Linn High Therm systems are applicable for manufacturing of the smallest components in small quantities as well as for the mass production of much larger components. **IH**

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