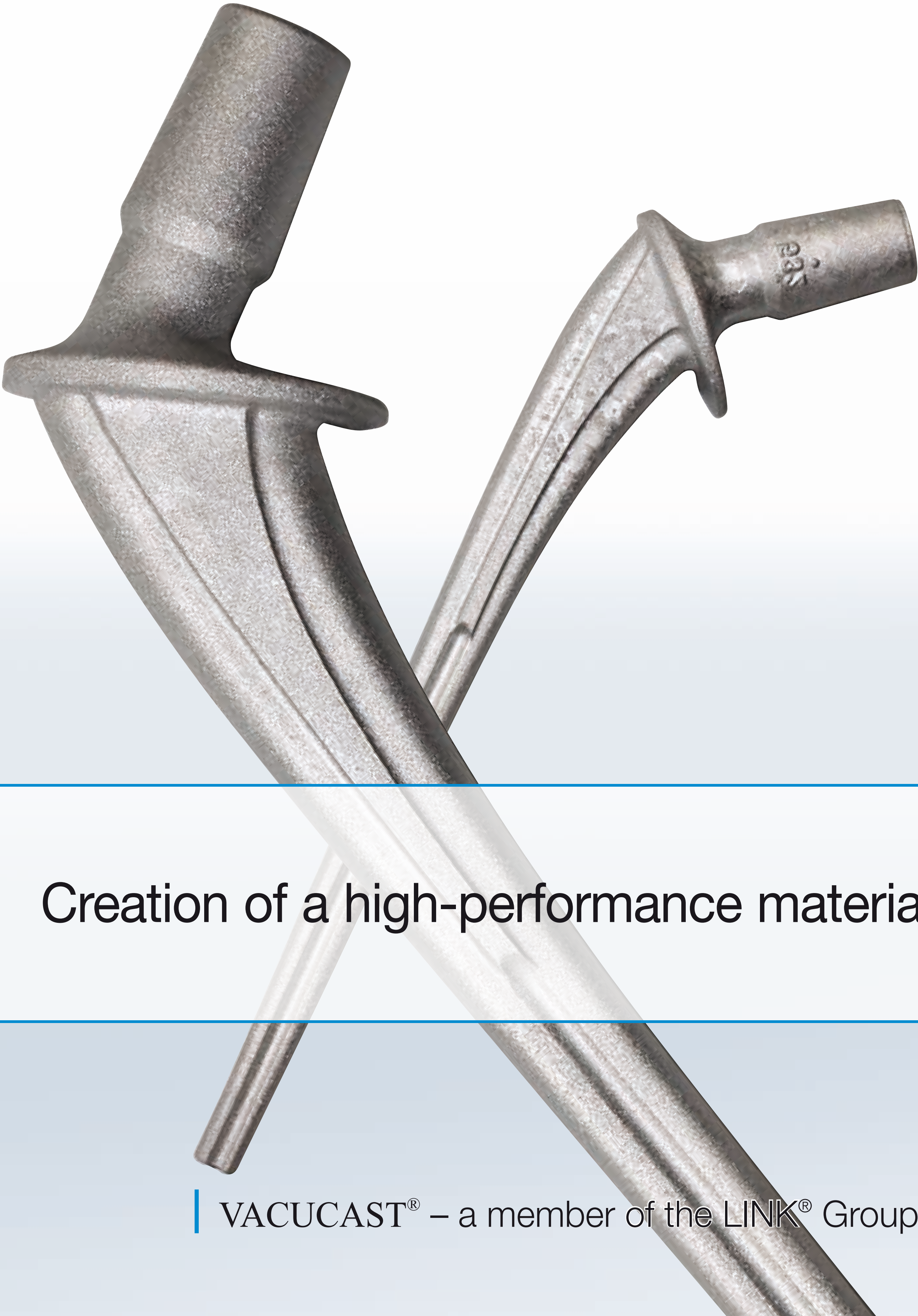
VACUCAST®



Creation of a high-performance material

VACUCAST® – a member of the LINK® Group

VACUCAST®

VACUCAST® Feinguss GmbH produces complex and high load-bearing knee and hip prostheses made of cobalt-chrome (CoCr28Mo6, ISO 5832-4 or ASTM F75) and titanium alloys (TiAl6V4, ASTM F1108) by means of investment casting.

This technique offers virtually unlimited design options and, given close-contoured production and thus high material yield, the economic production of prostheses and instruments is also guaranteed, even with low production quantities.

In order to achieve and guarantee the excellent mechanical properties and reliability of Link implants, e.g., SP II®[1] and C.F.P.®[2] hip prostheses, at VACUCAST® only high-quality materials are used and the entire production process is subjected to comprehensive testing. Furthermore, the cast structure is refined by customized subsequent compression and homogenization processes which further enhance the mechanical properties to render them non-anisotropic.

1 SP II Lubinius – survival rate of 95.9%; the Swedish Hip Arthroplasty Register 2011, page 74.
2 C.F.P. survival rate of 99.3% - Annual Report of Regional Register of Orthopedic Prosthetic Implantology, 2011, page 73

The casting process and subsequent compression

The solidification of alloys, i.e., conversion from liquid to solid metal, is associated with an increase in volume due to the higher density of the solid body compared to the molten metal. If the molten metal is in contact with the solidified area, the resulting volume deficit can be remedied. Thanks to the optimal casting design of the components and the casting clusters solidification pores which render the component weaker are generally avoided. Given the complex nature of this process, the formation of individual pores in the structure cannot be completely ruled out (Figs. 3, 4 and 7, 8).

To eliminate all risks, all VACUCAST® cast products made of cobalt-chrome and titanium are subsequently compressed in a state-of-the-art HIP system with a protective gas pressure in excess of 1000 bar for several hours at more than 1000°C (Figs. 9 - 12). Every imperfection (Figs. 3, 4 and 7, 8) within the cast is "forged together" under the high isostatic pressure in the system. This is possible as the high process temperature temporarily reduces the material strength and it can be pressed from the outside into the inner imperfections.
Every single implant is x-rayed before being dispatched in order to document the success of HIP treatment.

Biodur® (CoCrMo)

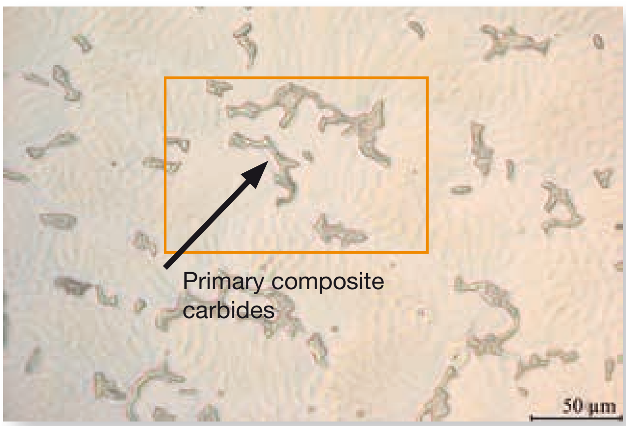


Fig. 1
Biodur® CoCrMo after casting without subsequent treatment.

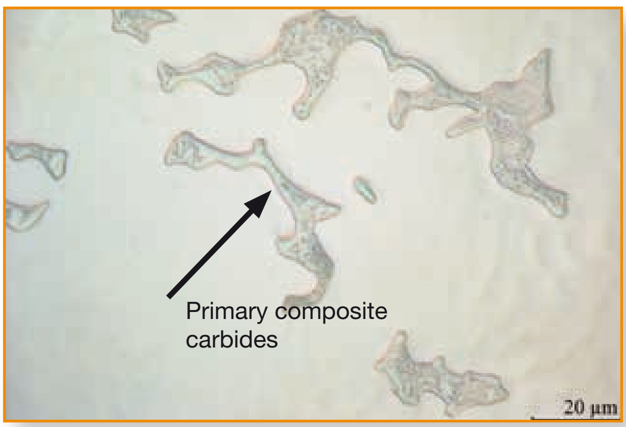


Fig. 2
Magnification of detail from Fig. 1
Large, angular primary solidified block carbides of this size and larger have a detrimental effect on the mechanical parameters, crack formation and crack propagation.

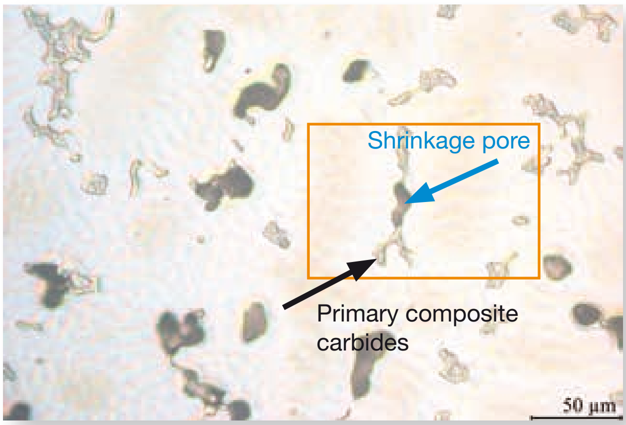


Fig. 3
If pores are formed when CoCr28Mo6 casts are solidified, these can be found in the proximity of primary carbides (gray) under the microscope.

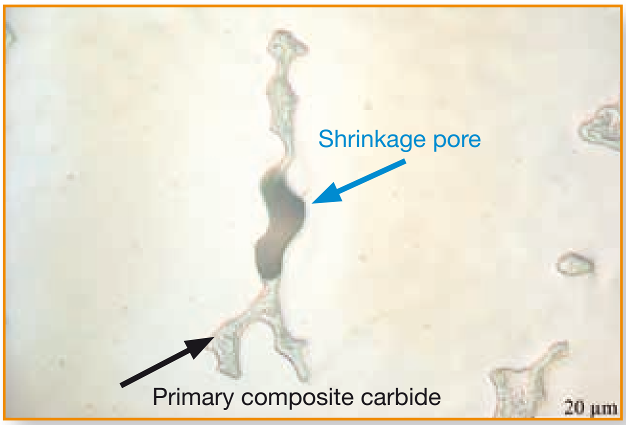


Fig. 4
Magnification of detail from Fig. 3
In this figure it can be clearly seen how an elongated primary carbide with a shrinkage pore in the middle is solidified.

Tilastan® (titanium aluminum vanadium)

Fig. 5
The microstructure immediately after casting without subsequent treatment of a Tilastan® TiAl6V4 cast alloy as per ASTM F1108. With optimal solidification, the volume deficit is balanced out by the subsequent flow of molten metal and a completely solid structure is ensured.

Fig. 6
Magnified view of the lamellar structure of Tilastan® TiAl6V4 immediately after casting.

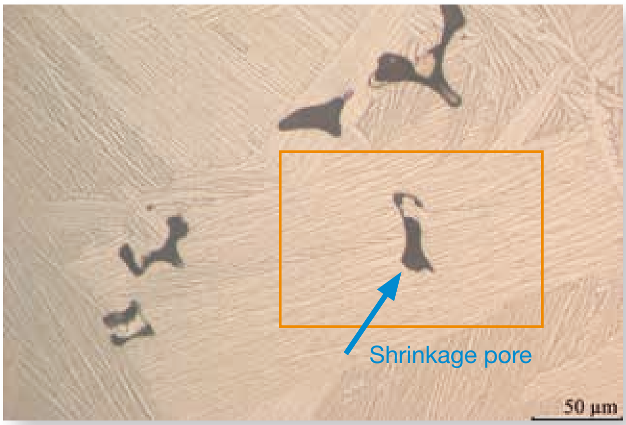


Fig. 7
The structure of TiAl6V4 is characterized by its lamellar nature comprising a α matrix and β phases. Possible casting pores are markedly different from the microstructure.

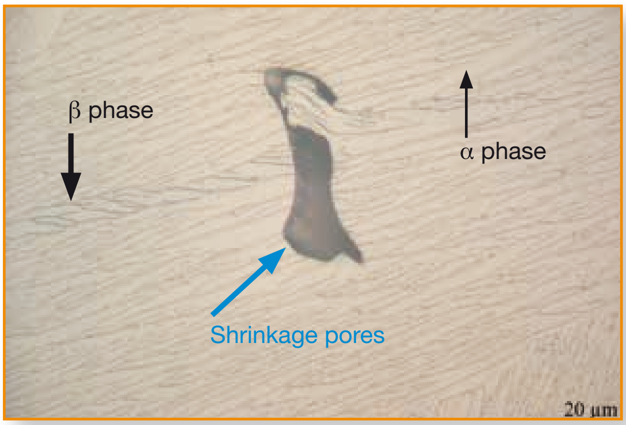


Fig. 8
Magnification of detail from Fig. 5

Optimization of the cast structure with HIP treatment

Biodur® (CoCrMo)

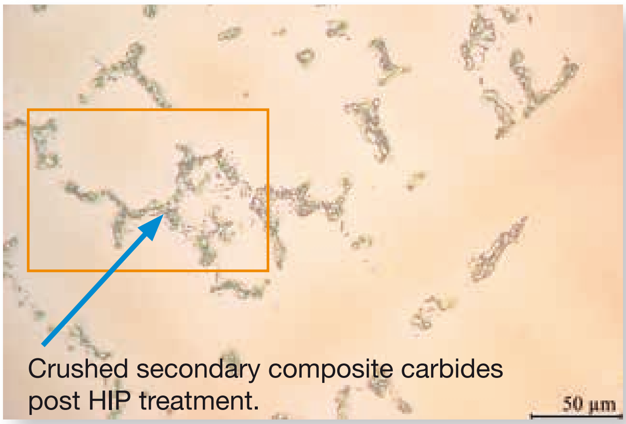


Fig. 9
CoCrMo cast alloy as per ASTM F75 / ISO 5832-4 with subsequent HIP treatment. There are still larger accumulations of round composite carbides.

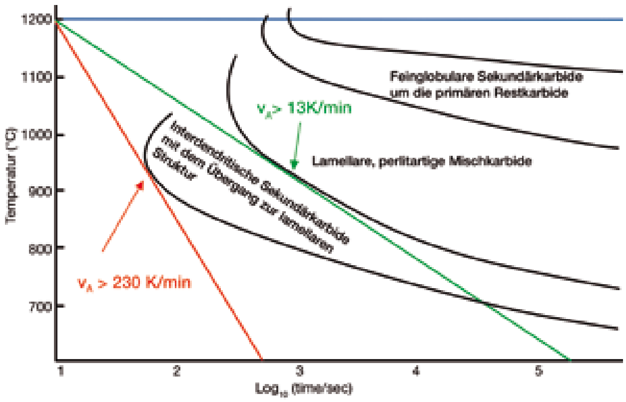
Fig. 10
Magnification of detail from Fig. 9

Tilastan® (titanium aluminum vanadium)

Fig. 11
Following HIP treatment, the structure of both the cobalt-chrome (9, 10) and titanium components (11, 12) is pore-free. Initial homogenization of the structural components has already occurred under the influence of the heat, this is evident by the broken lamellar structure.

Fig. 12
Magnification of detail from Fig. 11

Temperature-time-precipitation diagram in the HIP process for the secondary (Cr, Mo) carbides in CoCr28Mo6



= conventional HIP system
= state-of-the-art VACUCAST® system

Diagram 1
The temperature-time-precipitation diagram (TTP diagram) clearly shows that carbon is only precipitated as very fine secondary (Cr, Mo) carbides in CoCr28Mo6 when exposed to very high cooling rates in excess of 230K/min as possible in the new VACUCAST® HIP system.

Biodur® (CoCrMo), heat treatment

In order to homogenize and refine the composite carbides which are responsible for strength and hardness in the cobalt-chrome alloys, the cast pieces are annealed in special heat treatment furnaces at temperatures in excess of 1000°C under protective gas for several hours. Under these conditions, larger carbides partially dissolve or become smaller and rounder since the solubility of the structure for carbon increases at higher temperatures.
At the end of the homogenization phase, the cast pieces are treated in a quenching bath. This serves to "freeze" the state achieved.
Rapid cooling down to room temperature prevents the dissolved carbon from being taken up by the remaining carbides. The cooling rate with HIP treatment is shown in diagram 1.

If the cast structure is observed under a microscope, an inhomogeneous distribution of some structural components is evident. If the metal is prepared accordingly, superior individual precipitations within the grain boundaries are evident (Figures 1 and 2). Yet homogeneity and the size of the grains and precipitations are crucial for the mechanical properties of a component.
With finer and more homogeneous structures a higher strength and longer lifetime when subjected to loading can be expected (Fig. 15).

To achieve this optimal microstructure, all the cobalt-chrome and titanium cast pieces at VACUCAST® undergo the alloy-specific heat treatment described above.

Fig. 13
After HIP and heat treatment, the carbides are finely distributed in the cobalt-chrome matrix. This guarantees optimal material properties for the application.

Fig. 14
Magnification of detail from Fig. 13

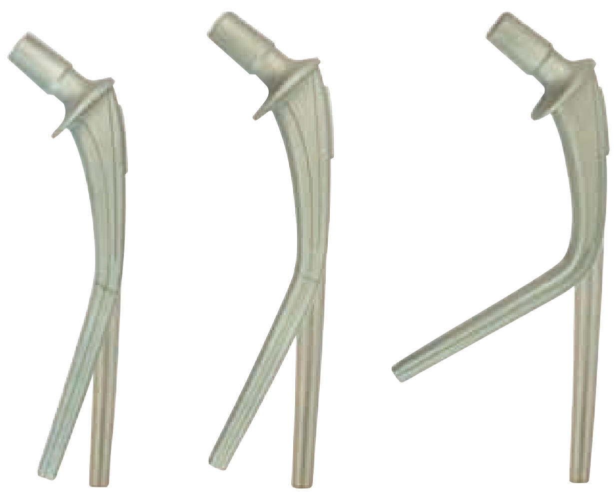


Fig. 15
The overview of bent SP II® stems illustrates the resistance of the cobalt-chrome material to failure following VACUCAST® refinement of the cast structure.
Maximum deformation until fracture increases from a bending angle of 16° in the as-cast state to 24° after HIP treatment and to 57° following HIP and the VACUCAST®-specific heat treatment.

Tilastan® (titanium aluminum vanadium)**, thermochemical treatment**

Optimization of the structure of our titanium cast blanks is achieved through complex thermochemical treatment in a vacuum or hydrogen atmosphere. It leads to an extremely fine lamellar $\alpha + \beta$ structure with superior mechanical properties.
Figures 16 and 17 show the change in size and distribution of the β phase within the α matrix.

The structure guarantees a long component service life and an extremely high degree of resistance to failure. A comparison of the fatigue strength with forged structures which normally have a globular structure with the same chemical composition (Figs. 18 and 19) clearly demonstrates the advantage of the heat-treated cast structure, Figures 16 and 17.

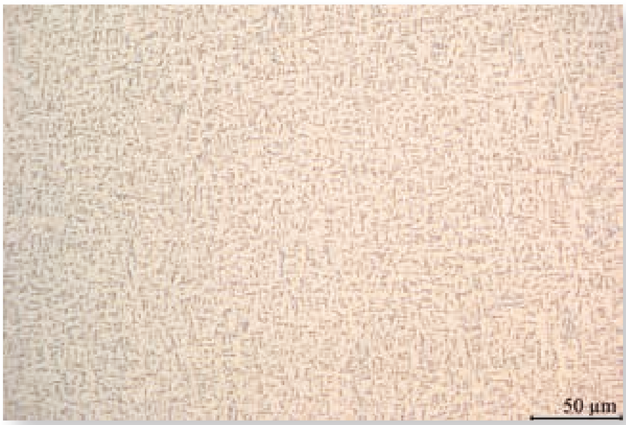


Fig. 16
After refinement by means of HIP and thermochemical heat treatment, the VACUCAST® titanium components have a very fine lamellar microstructure.

Fig. 17
Enlarged view of Fig.16
The $\alpha + \beta$ alloy has a basketwork structure here.

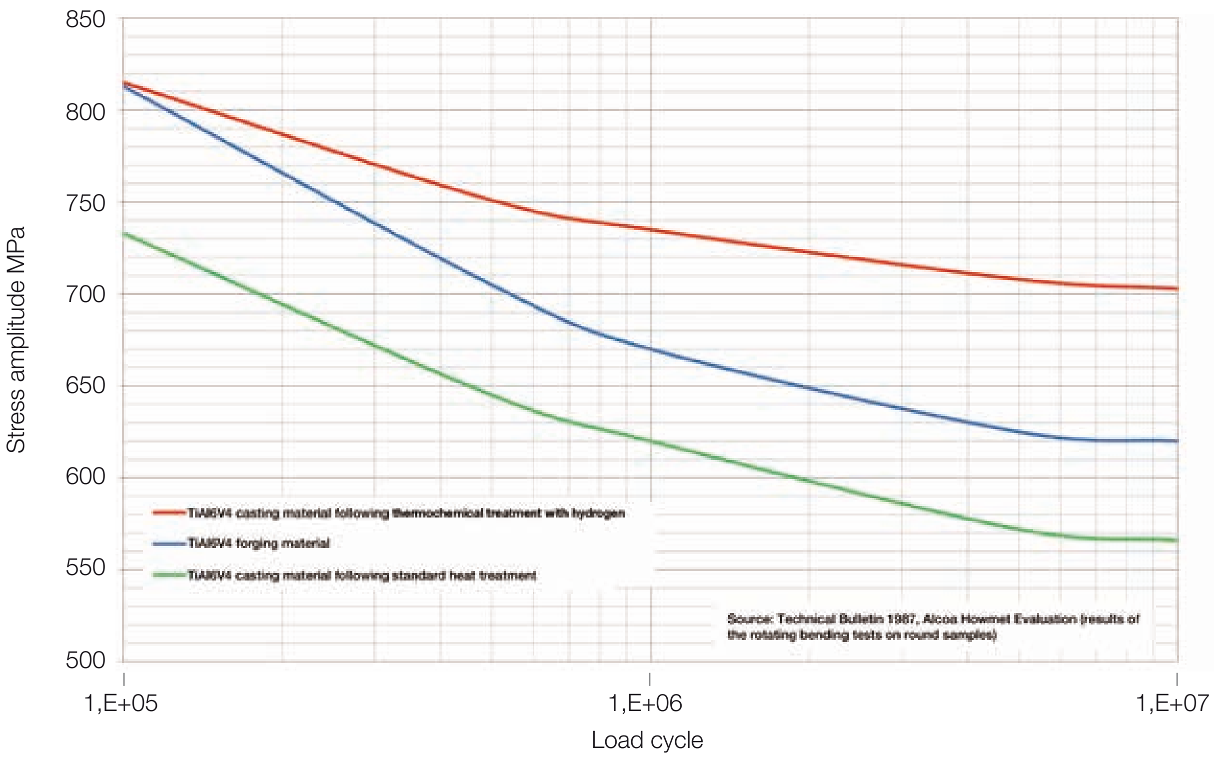


Diagram 2
Thanks to the targeted thermochemical treatment with hydrogen, the fatigue strength of Tilastan® TiAl6V4 casting material is improved compared to the standard heat treatment and is also significantly above the values recorded for forging material.

Biodur® (CoCrMo)

Fig. 18
Compared to a globular (Fig.18) or bimodal forging structure (Fig. 19), the VACUCAST® cast structure (Figs. 16 and 17) has a minimal tendency for crack propagation due to its very fine basketwork lamellar structure.

Titanium forging structure

Fig. 19
Bimodal forging structure

	R_m N/mm²	$R_{p0.2}$ N/mm²	A_5 %	Z %
Forging material	950	870	16	40
VACUCAST® Tilastan®	1000	900	12	25

Table
The comparison of the mechanical parameters of VACUCAST® Tilastan® with typical values for TiAl6V4 forging materials shows the outstanding properties of the investing casting material following the thermochemical treatment developed by VACUCAST®.

R_m = Tensile strength
$R_{p0,2}$ = Yield strength
A_5 = Yield stress
Z = Ultimate strain

Grading in Biodur® cast products

The fine grains and their homogeneous distribution reduce the crack and crack propagation risk.

Fig. 20
The illustration shows a macro etched SP II® stem, clearly showing the grading and the grains.

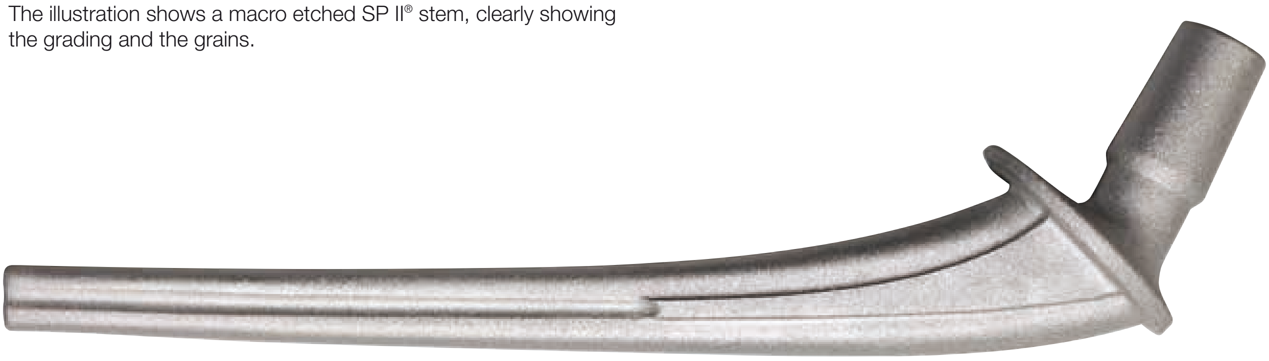


Fig. 21
The above macro etched SP II® stem shows the ideal fine-grained Biodur® structure.

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