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PRODUCTION OF CAST TiAl- EXHAUST VALVES FOR PASSENGER CARS

M. Blum, H. Franz

ALD Vacuum Technologies AG, Hanau, Germany

Abstract

Nearly two years ago a production scaled prototype furnace for TiAl- automobile- valves has been put into operation by ALD at ACCESS in Aachen Germany. The project was supported by the German federal ministry for education and research.

Today more than 12,000 valve planks each were cast under fully automatic process control. The manufacturing process in the prototype plant allows the production of 50 parts per pouring. An automated 2 shift operation under production cycle times was carried out in autumn this year. First results will be explained. A key for future cost reduction is the recycling of revert TiAl material. The recycling possibilities will be discussed.

Also the quality assessment data will be shown in the paper to be presented. These data will include LCF testing at working temperature, X-ray inspection results, fracture toughness, metallographical inspection, chemical composition and final application in the engine.

The whole ongoing work is focused to demonstrate the price targets of the automobile industry.

Introduction

ALD Vacuum Technologies AG realised together with 8 other partner companies (Table 1) and research institutions the development of a new production process for γ-TiAl exhaust valves. To meet the cost target for the substitution of high end steel or nickel-base superalloys valves a new process technology for the economical production of Gamma TiAl-valves has been developed. The most important cost cutting effect can be achieved by establishing an optimised recycling process for the revert TiAl material. This step will be explained later.

Table 1. Project partner

ALD Vacuum Technologies AG	63450 Hanau	Germany
ACCESS e.V.	52056 Aachen	Germany
TRW Motorenkomponenten GmbH	30881 Barsinghausen	Germany
GfE Metalle und Materialien GmbH	90431 Nürnberg	Germany
Institut für Elektrothermische Prozeßtechnik	30167 Hannover	Germany
Adam Opel AG	65423 Rüsselsheim	Germany
Audi AG	85045 Ingolstadt	Germany
Bayerische Motorenwerke AG	80788 Muenchen	Germany
Ford Forschungszentrum GmbH	52072 Aachen	Germany
Volkswagen AG	38436 Wolfsburg	Germany

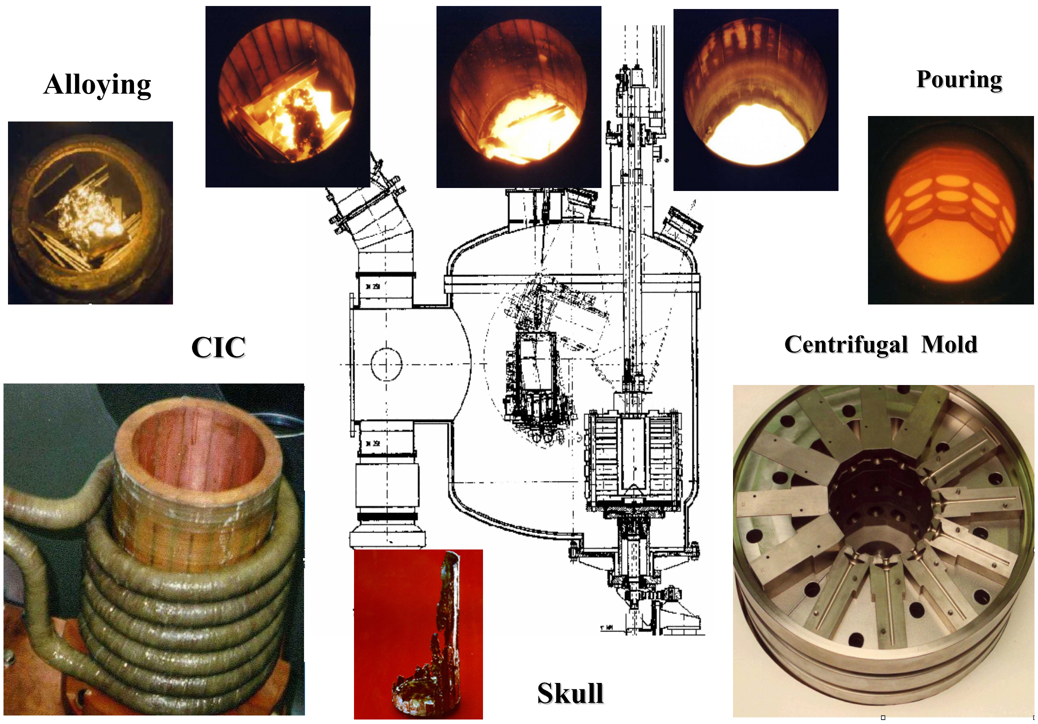

Figure 1. Process visualisation

The new integrated centrifugal casting process comprises an improved cold-wall-induction crucible (CIC), a preheated metallic mold and a manipulating system for charging the melt stock and unloading the cast valves without breaking the furnace atmosphere.

The process principles, which were developed in a previous project are visualised in Fig. 1 [1]. On the left hand side the melting material will be charged in a CIC, molten down and finally homogenised. The liquefied alloy on the right hand side will be poured into a rotating preheated metallic mold. The valves produced in such a manner impressively outperform the mechanical properties demand by the automotive companies. These facts are proven by various mechanical tests and by several engine test runs.

Based on the target for the R & D – work of the present project an integrated highly automated, reliable centrifugal casting process for mass production was established in a prototype plant for a maximum manufacturing capacity of 600,000 valves per year.

The valves produced in this prototype plant were intensively investigated as reported later in this paper. This is still an ongoing process to prepare the necessary data base for an implementation of these γ-TiAl valves.

In parallel the automotive companies participating in the project are working on the reengineering of the valve-train-systems to utilise the full potential of the high temperature capable, light weight γ-TiAl valves [2,3]. These features allow a higher rotational speed, change in the combustion regime of the engine and a reduced noise level.

Manufacturing Process

The high integrated and automated process offers several options for the used charging material:

a) Starting with virgin Ti scrap sheets, aluminium granules, Nb-, Cr-master alloys
b) Compacts
c) Premelted material
d) Ingots of the decided γ-TiAl alloy

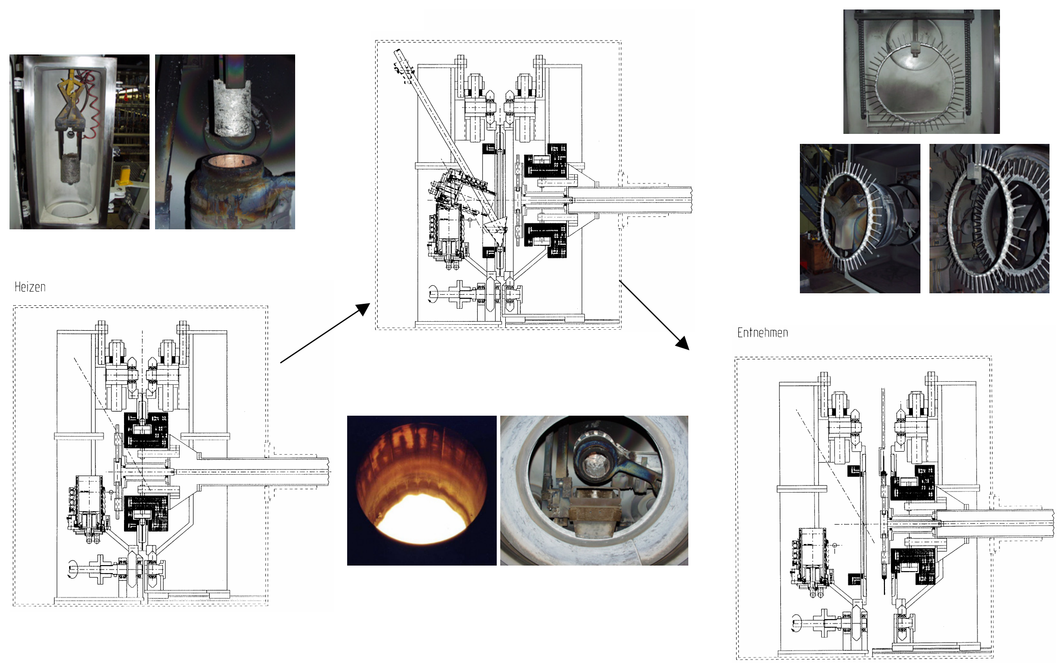

Figure 2: Present manufacturing process

A whole process cycle is visualized in Fig. 4 The melting material is pinched in a charger (left side) inside a charging chamber, moved into the cold wall induction crucible (upper part left side). The heater is inside the permanent mold (lower part left side). Melting inside the CIC and mold heating is carried in parallel. The liquefied and homogenized melt is poured into the rotating centrifugal mold (center part of Fig.4). After pouring the rotating mold is stopped and opened (right side). Therefore, a stretch out device positions the cast part ring (upper part right side) before the parts will be transferred by a manipulator (upper part right side) into a reloading chamber. Then the next process cycle can be started without breaking the furnace atmosphere. After a short cool down time the valve ring is transferred in a water jet cutting machine (Fig. 5). 50 valves can be produced in one casting step. Up to now about 350 casting trials were carried out – among these 5000 cast valves were investigated.

Figure 3 Water jet cutting machine

Test Run at Production Scale

To demonstrate the production capability of this prototype furnace an automated 2 shift operation under production cycle times was carried out for approximately 2 weeks. Base for the commercial calculation was a tap to tap time of 30 minutes whereas 50 valves bodies will be produced per pouring. In resulting cycle times of less than 23 minutes could be achieved, which allows an increase in the productivity by more than 20%.

The service of the furnace wasn´t necessary after every shift. For safety reasons an inspection by opening the main chamber was always carried out after the second shift or with other words after 30 to 34 casting trials, a inspection became necessary.

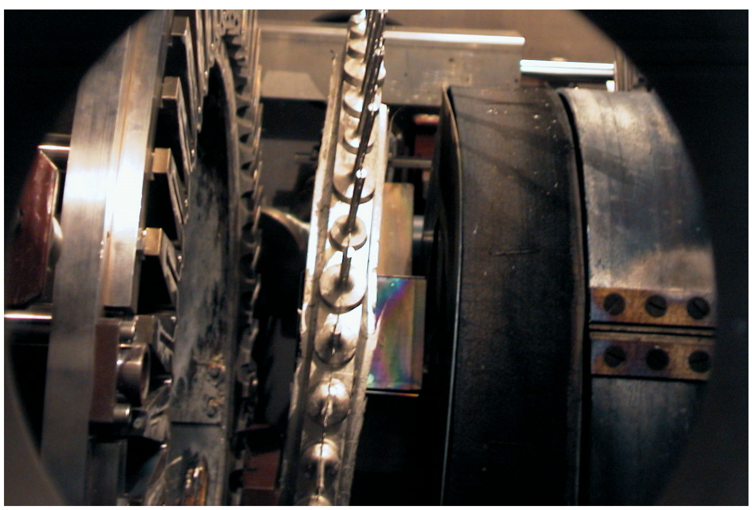

Figure 4: Cast valve ring

In total 142 castings were carried out under the above mentioned conditions. 7100 valve bodies were produced in total under identical processing parameters. The average yield was above 96%. As step of the automated process shows the opened permanent mould with a ring of cast valves in a stretch out device prior to the transfer into the reloading chamber.During the process cycles the operator acting was reduced to two actions: Charging new material into the cold wall induction crucible and moving the ring of 50 cast parts out of the chamber.

Recycling

The mass balance in the present stage of the project is visualised in figure 5. It is evident that a recycling of revert scrap will be necessary to meet the price targets of the automotive industry.

Today for titanium and titanium alloys the hearth melting techniques either by plasma arc melting or by Electron Beam melting is state of the art.

An typical EBCHR-furnace which will be part into operation by ALD at Baoji works in China in 2004 is shown in figure 5. Smaller quantities of revert scrap mixed with virgin material can be also processed in the classical Vacuum Arc remelting furnace. In the present situation γ - TiAl intermetallic compounds of different compositions are used, but the available scrap quantities aren't high. Therefore the above mentioned recycling process for titanium alloys can not be used for γ - TiAl.

For our needs a new recycling process had to be defined, whereas 40% scrap of the specific used alloy together with 60% origin material will be charged into a very simple cold wall induction melting furnace and liquefied for a very short time. Than these ingots will be transferred into the centrifugal casting furnace.

The big advantage of this step will be the direct use of scrap material which has to be crushed and washed. No additional processing became necessary. The composition of the scrap e.g. the aluminium contents very reproducible because of the highly automated and reproducible casting process.

A high cost cutting effect of 40% regarding the material price could be achieved if this special recycling process will be added.

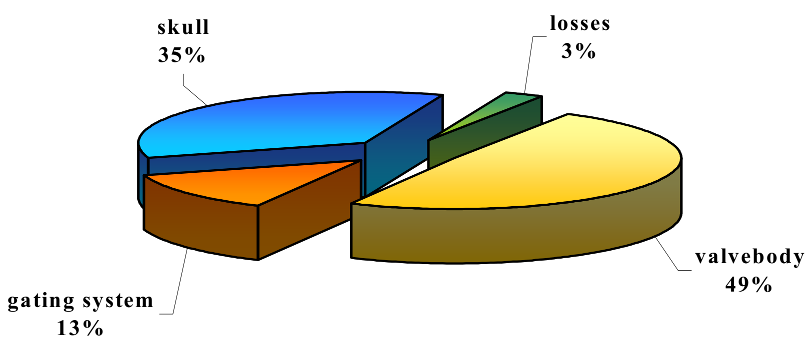

Figure 5: Preliminary Mass balance of the casting process

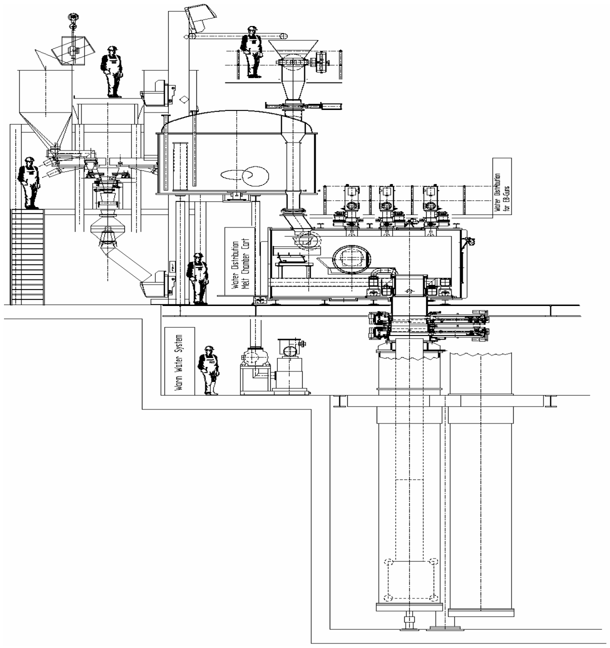

Figure 6: EB-Cold Hearth Remelting Furnace

- 4 KSR 600 EB-Guns 15 A/45 kV
- High frequency deflection
- Beam path length up to 1.7 m
- 4 oil diffusion pumps
- Hearth and ingot trolley system
- melt rate up 1000 kg / hour
- preheated granual feeder
- electrode feeder
- slab 1340x370mm/53”x15”
- Ingot dia. 736 mm/30”
- hearth size
- length 1.8m
- width 0.6 m

Quality Assessment of the Cast Valves

For process qualification and valve quality documentation a database was established. To define and control the valve properties a number of characteristic mechanical properties were also stored. These characteristic values were provided by valve investigations listed as follows:

- X-ray inspection (temporary)
- Chemical analysis
- Plastic elongation
- Yield strength
- Tensile strength
- HCF-testing

X-Ray Inspection

In the present project face, all cast valves are inspected by x-ray (Fig. 6). A scanning device is used where 11 parts can be scanned in a few minutes. The minimum pores which can be detected have a size of less than 0.1 mm. The digital scan data are controlled by an automated image analyzing system.

To overcome the high x-ray inspection cost for each single cast valve and to optimize the yield up to 98% a special HIP-cycle has been developed in a so called design of experiment (DoE) study. The processing temperature is relatively low to keep the as cast structure e.g. the lamellae spacing. This works because of the casting process immanent small pore size and their location in the center axis of the upper third of the valve stem. The overall cost for this HIP-process is less than the added cost for the x-ray quality inspection and the reduced yield.

Chemical Composition

For each melt trial a chemical analysis is carried out to monitor the composition and homogeneity of the alloy. The composition can be achieved quite exactly e.g. for aluminum in a deviation bandwidth of about +/- 0.5 atomic percent. This narrow bandwidth is up to now better than the deviation range, which is guaranteed by material suppliers for ingot material.

The narrow band with is a very important base for the targeted recycling process as explained in chapter 4.

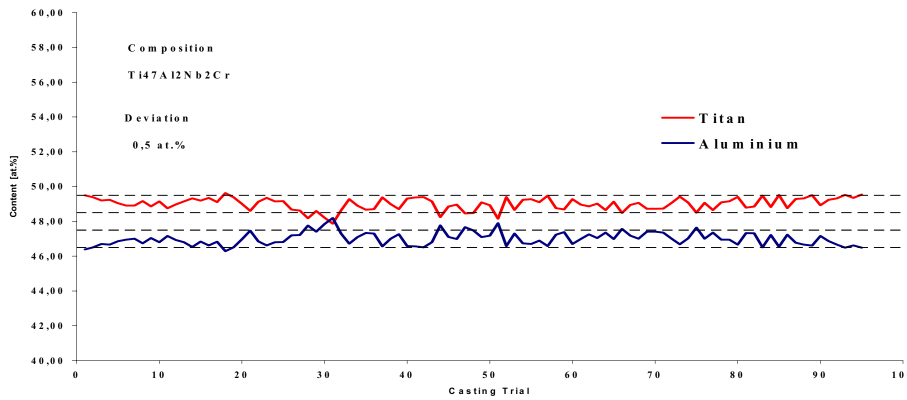

Figure 7: Chemical composition versus test trials

Mechanical Properties

All mechanical properties were measured for parts cast in the new prototype plant while a process optimization was carried out. Therefore the data indicate that the process has a sufficient operation window in which the cast part quality is above the mechanical properties as specified by the automotive companies.

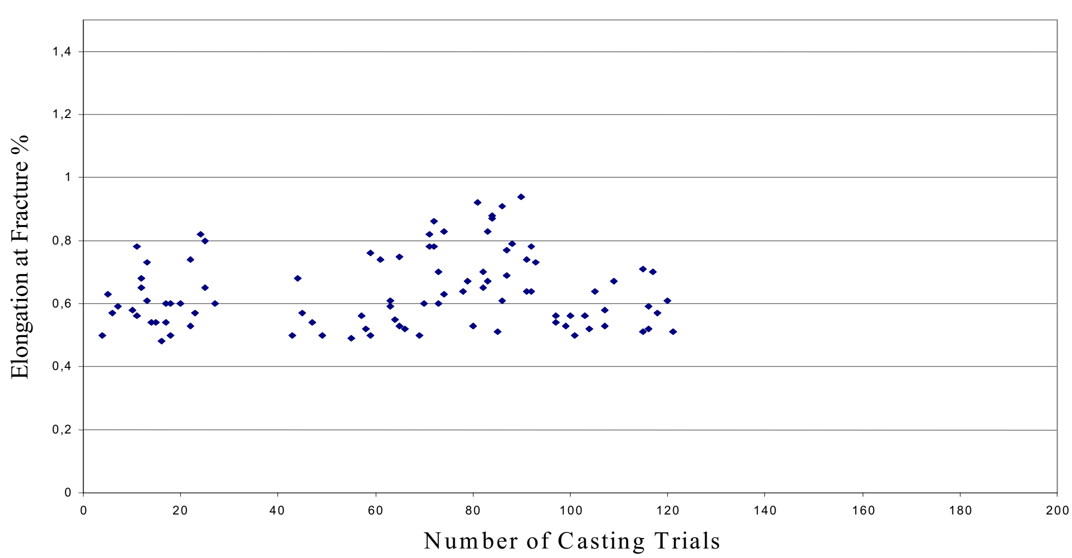

Figure 8: Elongation at fracture at room temperature

The plastic elongation over the number of castings is in a range of 0.5 % to 1 % (Fig. 8). These values are sufficient for an application as automotive valve and could be achieved without any subsequent heat treatment process.

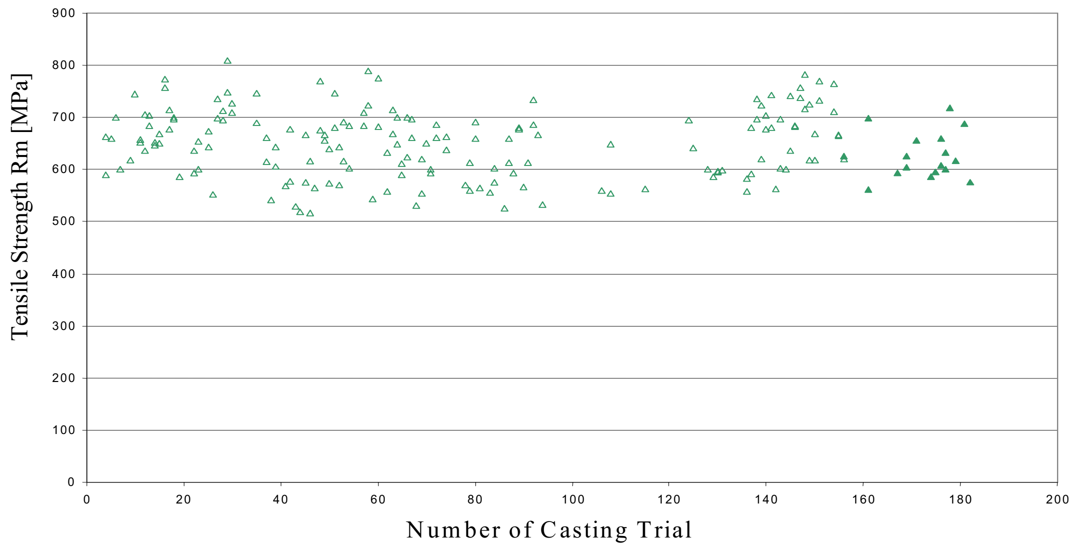

Figure 9: Tensile strength at room temperature

Fig. 9 shows the and tensile strength at room temperature as a function of casting trials. All yield strength values are above 500 MPa which was specified by the engine manufactures. By considering that also process parameters were varied 600 MPa can be achieved with an γ - TiAl alloy of an older type without any problems.

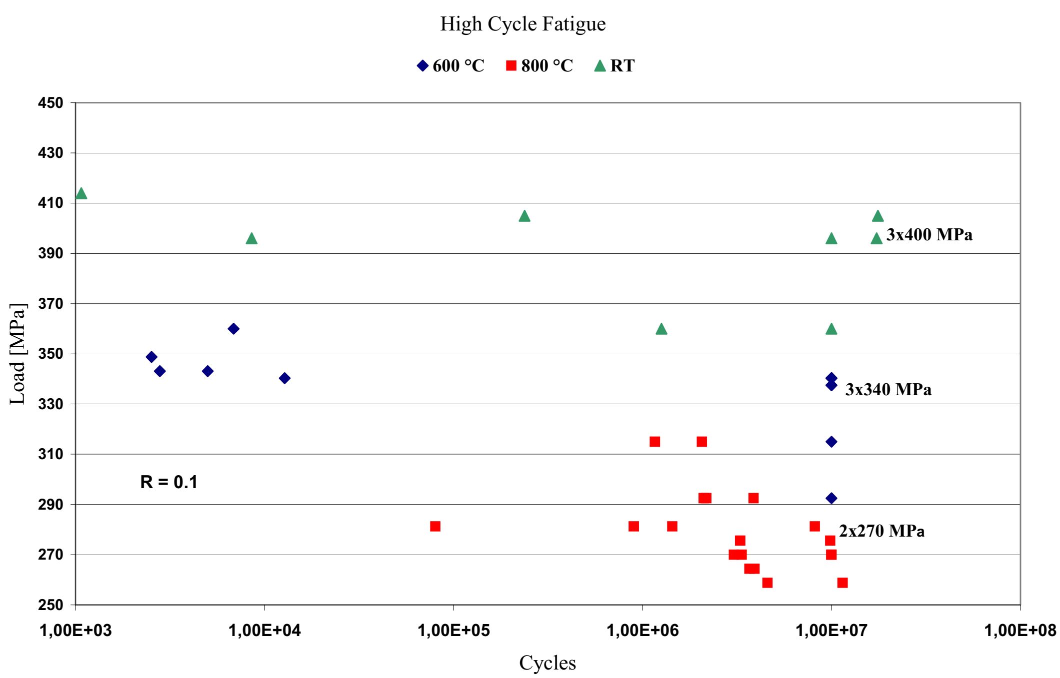

Figure 10 High cycle fatigue

The high cycle fatigue (HCF) testing data are shown in Fig. 10_for 3 temperatures (RT, 600°C, 800 °C) for several loads. More than 1 x 10^7 load cycles could be realized for loads of 400 MPa at RT, 340 MPa at 600 °C and 270 MPa at 800 °C. These HCF testing data were realized for random samples of valves out of 50 casting trials after a HIP-process.

Conclusion and Outlook

The quality assessment of the cast valves produced under production cycle conditions are on the way. All parts will be processed in the special Hip-process, which keeps the special casting structure of the parts. This means e.g. the grain sizes and lamellae spacing.

Additional recycling testruns will be carried out, based on the process explained in the presented paper to demonstrate the cost cutting benefit and the quality of the cast parts made out of this material.

During the next year the automotive companies will be provided with larger number of test valves.

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