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Advantages are not only Environmental

Improved Properties of Aluminium Cast Parts Through the Use of Inotec Cores

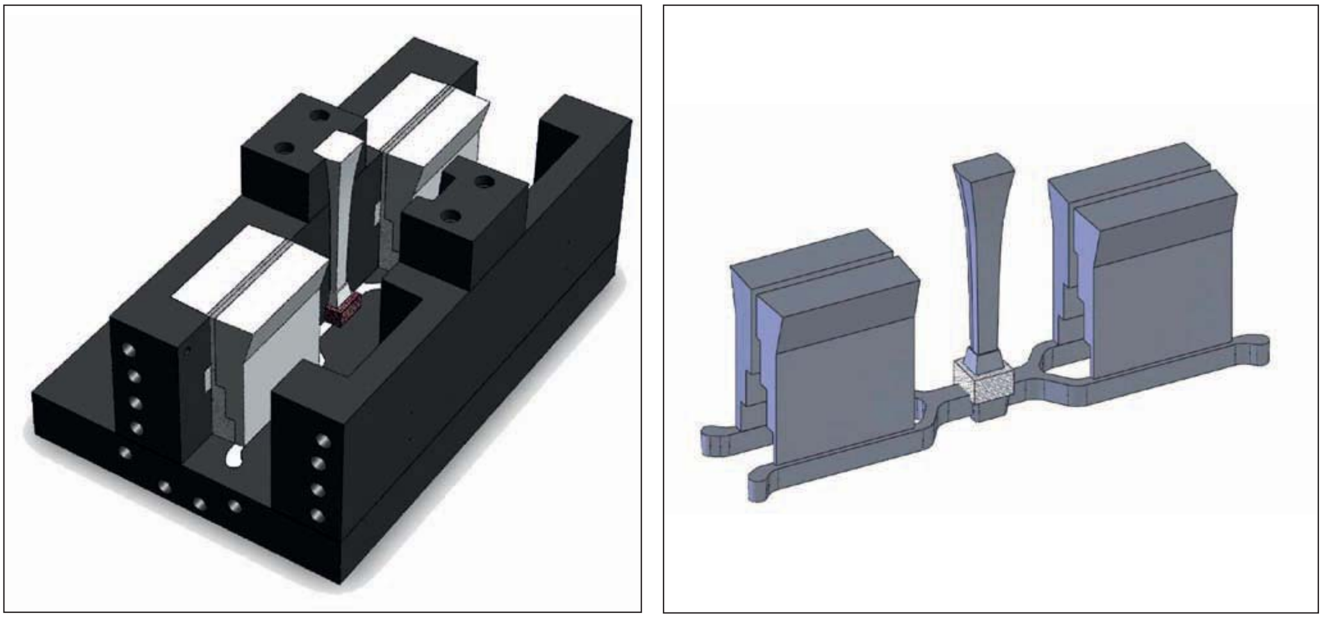

Figure 1: 3-plate tool with central casting and virtual casting of the stepped plates

When foundries become interested in inorganic mould or core manufacturing methods, this is usually motivated by the possibility of reducing emissions. In fact, the use of inorganic binder systems is not only bene- cial to the environment.

For instance, advantages in productivity and quality can also be seen in application for series production. The use of the Inotec inorganic binder system not only increases tool availability, e.g. by reduced cleaning Intervals for the core box and die mould, but also signieantly reduces the cleaning costs for castings, where condensation e.g. of phenol binders is a key factor.
However, one crucial observation was that castings manufactured using the Inotec method show less porosity. This was the starting point for a large-scale project in which the impact of the inorganic binder system on the material properties of typical cylinder head and block alloys were examined.

Comprehensive series of Investigations were designed in collaboration between Ashland-Südchemie-Kernfest GmbH, Hilden, Germany and the Austrian Foundry Research Institute in Leoben, Austria. In addition to the simulation and construction of the tool developed specially for this Investigation, consisting of a core box and gravity die casting mould, metallographic examinations and the determination of static and dynamic material testing was also performed. The casting trials were conduducted with Inotec cores and cold-box cores simultaneously, and the results were assessed in a comparative manner.

Casting Complex Geometries

Inorganic binding agents have a long history and were used successfully in many processes. Today inorganic methods are making a comeback in foundries. But how exactly does Inotec binder differ from conventional sodium silicate binders?

The basis of the binder is still a silicate system, similar to conventional sodium silicates. This has the advantage that no side-products apart from water can be released during core manufacture or casting, and emissions are limited, in contrast to the cold-box sector, for instance.
Conventionally the use of sodium silicates is mostly applied to relatively simple geometries. Reasons for this are the poor flow properties of the sand mixture and the hardening process with CO_2. The latter involves two disadvantages: low final strengths and inferior disintegration after casting.
In contrast, Inotec shows very good flow properties, meaning that even complex geometries such as delicate cooling jackets can be formed. Artificial hardening is by a drying process, which requires the use of heatable core boxes (approx. 170°C) and hot air flushing.
By using special additives, known as promoters, system properties such as initial strength, cast surface condition

(no coating, no talcing required) and thermal resistance can be controlled in a targeted manner.
The following advantages are shown in series production application:
- Environment: No emissions during core production, low emissions during casting
- Quality: No condensation on the cast part, less cleaning work
- Economy: Very little soiling of the core box and die mould, therefore a very high availability of the tools and higher casting output
- Technology: Improved material properties as a result of less porosity in the cast part.

The basic concept for the investigation consists of temperature controlled, vertically split ingot mould with two symmetrically arranged moulding posts and a central gating systeme with a filter **(figures 1 and 2)**. Simultaneously an Inotec core is inserted in one of two core prints and a cold-box core is inserted in the second.
The cores are designed in a stepped manner, and the casting results in four stepped plates. From the stepped plates, the impact of different core strengths, wall thicknesses of casting and binder systems on the microstructure and the mechanical properties can be assessed.
The core box for manufacturing the Inotec and cold-box cores can be temperature controlled by using electric heating catridges and/or all-over hot plates. During core shooting excessive gases are vented trough slotted dies. Temperature monitoring and temperature control were conducted via a thermocouple in the sidewall of the core box. The core is positioned in the ingot mould and secured against floating by means of two core prints.
The specific heat capacity, the thermal expansion and the temperature conductivity were measured in the temperature range from room temperature to 800°C as well as the density at room temperature were measured for the Inotec core and the cold-box core. From the data obtained, the thermal conductivity and the density as a function of the temperature from room temperature to 800°C were calculated. The thermophysical data were directly incorporated into the mould filling and solidification simulation with Magmasoft 4.4.

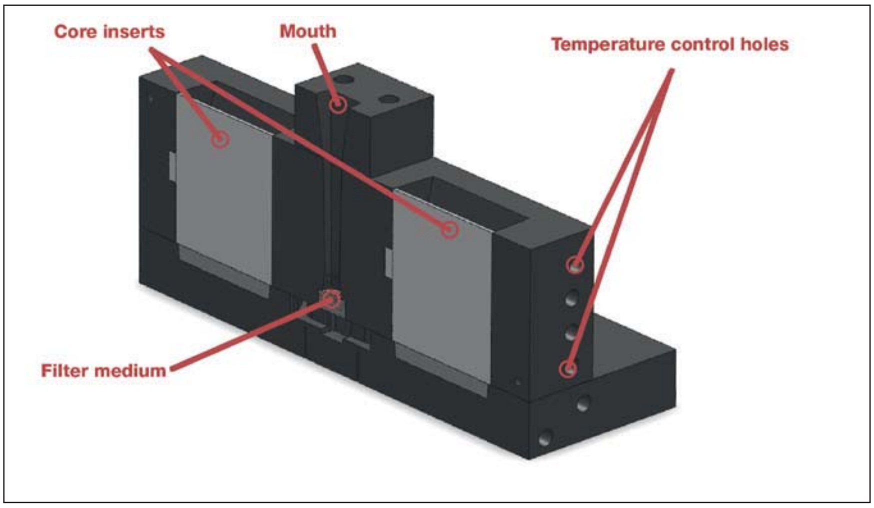

Figure 2: Full-section view of a dual-step plate die mould. Left die half with Inotec core, right die half with cold box core.

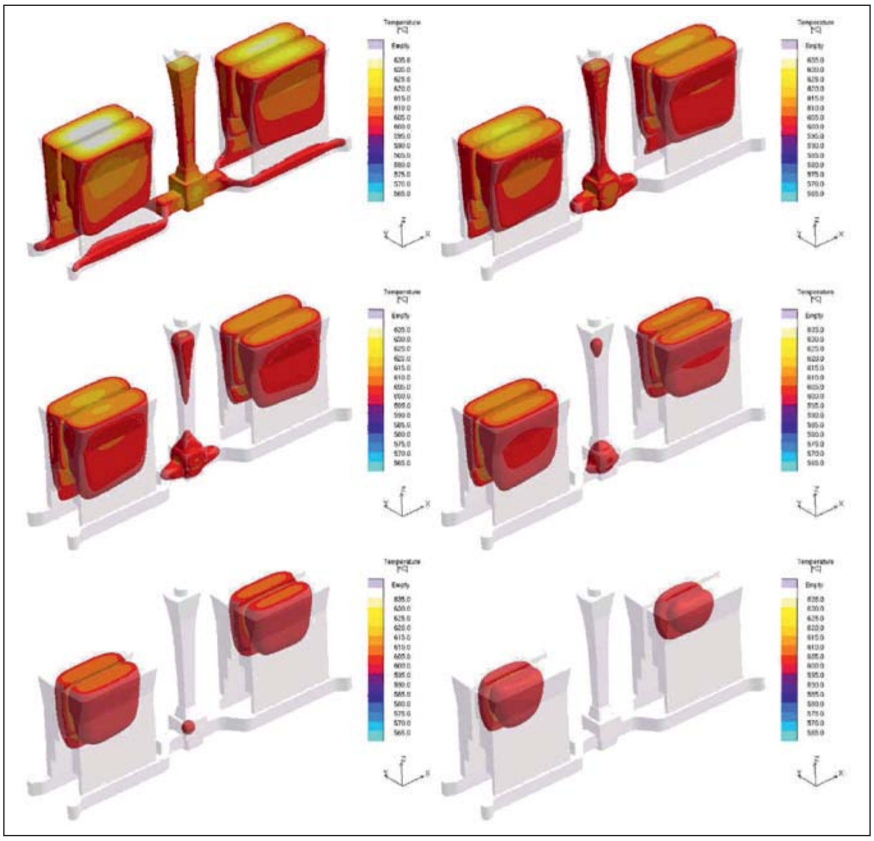

Figure 3: Solidification simulation: Comparison between Inotec core (left) and cold-box core (right)

Figure 3 shows the comparison of the solidification and solidification speed between an Inotec casting on the left and the cold-box casting on the right (already solidified areas are faded out). In the colour-coded temperature distribution, it can be seen that the molten metal of the casting with the Inotec core is around 5°C hotter than that of the cold-box core at the same solidification time. The difference in the local solidification time TE is only 1 to 2 s over the local solidification time of 100 s. The local solidification time is a key factor in determining the secondary dendrite arm spacing SDAS via the relationship SDAS = k*TE1/3 [1], where k is a material constant. In general, a small SDAS leads to good static and dynamic mechanical properties. However, as the already marginal difference in the local solidification time is only incorporated in the SDAS via the cubic root as described above, the expected Influence Is minor.

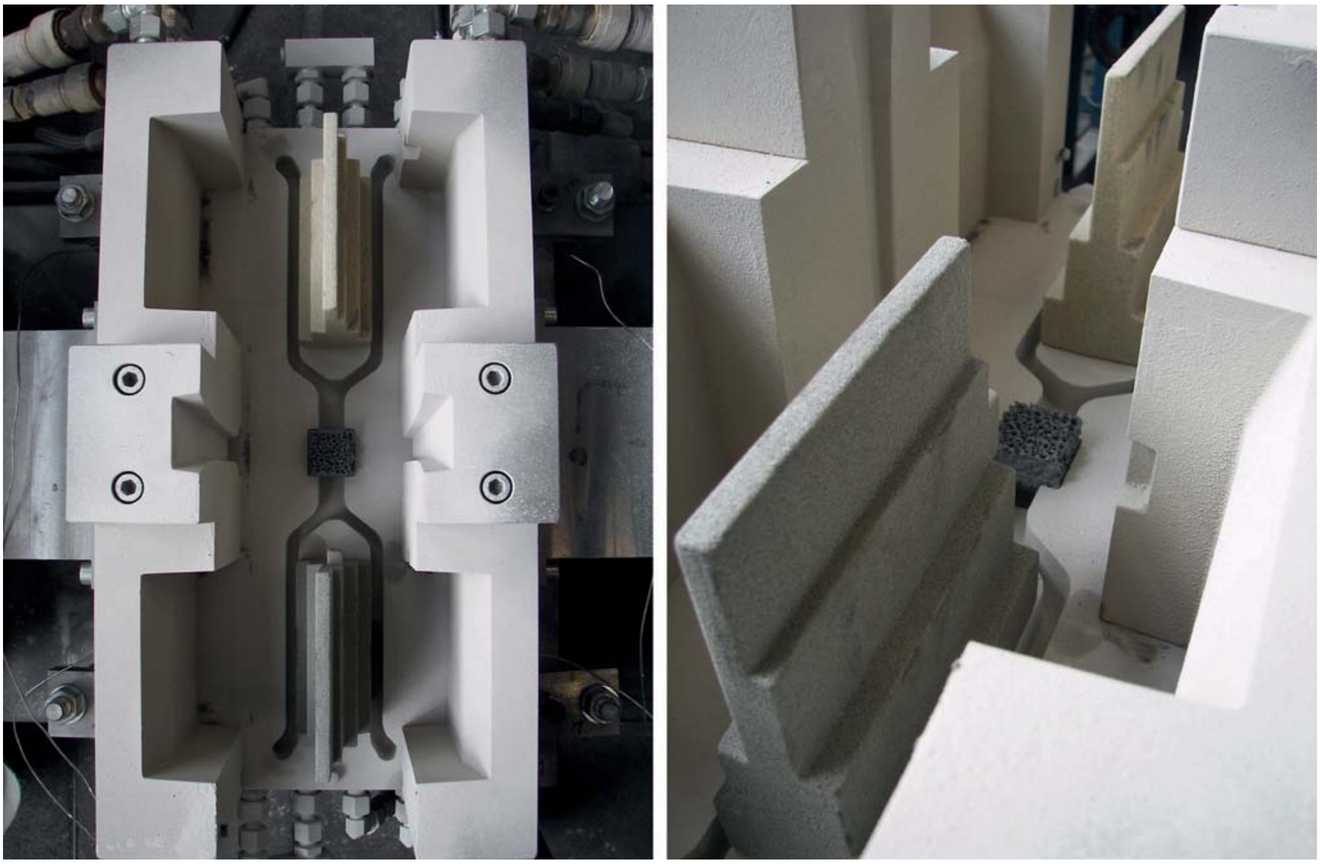

Figure 4: Test setup: Inotec core at the front, cold-box core at the back

Figure 5: Core variants 1 (for fully enclosed) and 2 (for cores with a free surface to air)

No Emissions - No Odours

150 kg of the alloy EN AC-Al Si7Mg0.3 were loaded into a resistance crucible furnace and heated to the casting temperature of 730°C ± 5°C. After melting, the molten metal was cleaned by means of rotary degassing (impeller). The molten metal was purged with argon for 6 min, with a flow quantity of 6 l/min. The control of the molten metal quality was done by reduced pressure test, and the density index was 1.2 %. The molten metal quality thus corresponds to the state of the art in foundries, and the molten metal is largely free of hydrogen and oxides. Consequently, the porosity arising in the cast part is not caused by poor melt quality, and results mainly from the released core gases.

The die halfs clamped on the die-casting machine as well as the base plate were coated with an insulating zirconium oxide coating **(figure 4)**. Both sides of the dual-step die mould were preheated to 280°C ± 5°C using a dual-circuit temperature device. The ingot mould temperature was calibrated and controlled during the castings by four K-type class I sheathed thermocouples. The thermocouples were located in boreholes that were positioned at a distance of 5 mm from the inside contour and centrally to the die mould wall.

To obtain constant and reproducible casting conditions, the mould was always opened and the sample taken when the die mould temperature had fallen to 320°C after a maximum temperature had been exceeded. The next casting was not cast until the die mould had been cooled down to 280°C by means of a temperature control unit using oil. Consequently, regular cycle times of approx. 360 s were obtained.

As was previously illustrated in the simulation (see Fig. 3), the Inotec core was always positioned on the left and the cold-box core on the right in the ingot mould. The first casting series were cast with an open core, i. e. they had free surface to the surroundings.

For the second casting run, the cores were cut off in the last step just above the core print and then fully surounded by the mould forcing gas Into the melt **(figure 5)**.

All castings (plates) were subjected to a T6 heat treatment (solution annealing – quenching – artificial ageing). The parameters for heat treatment used were chosen according to literature [2] for the alloy EN 1706 AC-Al Si7Mg0.3.

Significant fume generation of the cold-box cores was particularly noticeable during casting **(figure 6)** above the cold-box core. In contrast, no fume or odour nuisance was generated by the Inotec cores. On each moulding post where the cold-box cores were inserted, a resin layer of organic condensates formed on the sides of the die halfs after only 15 castings **(figure 7)**. In comparison, only minor deposits were identified on the die in the area of the inserted Inotec cores **(figure 7)**. As a result of the significant resin formation, the maintenance intervals of the tools in industrial operation when using cold-box cores must be reduced.

Figure 6: Strong emissions of the cold-box core (open core)

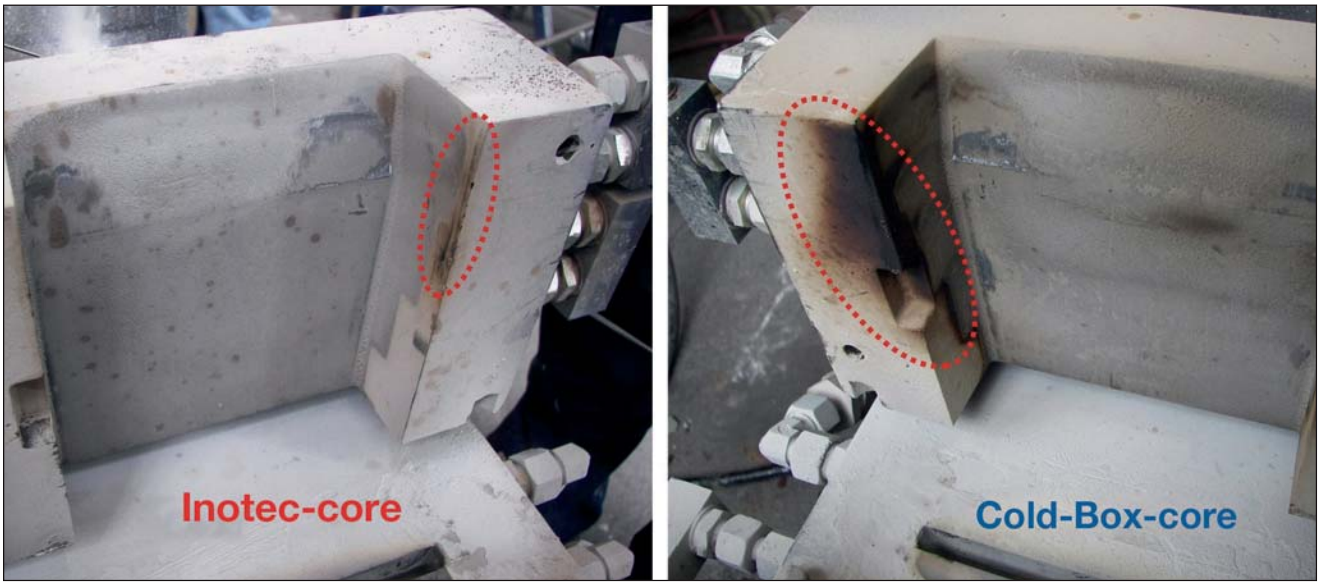

Figure 7: Resin formation due to organic condensates by using Coldbox cores

Excellent Mechanical Properties

For the structural examinations, metallographic samples from each step of the casting were prepared from the plate sections, embedded in synthetic resin, ground and polished. A quantitative image analysis system, analySISFive, was used to determine the porosity.

The microstructure of the examined cross section is characteristic of this alloy and consists of the light (α pri-

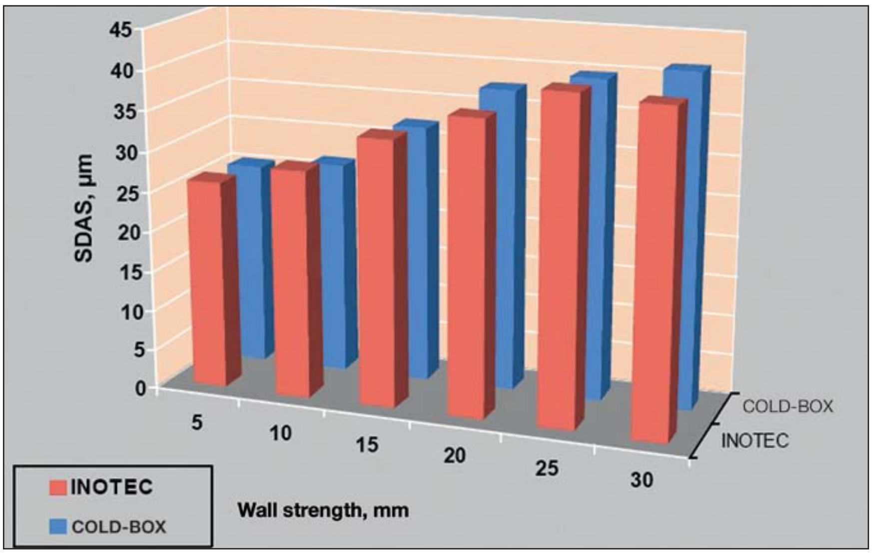

Figure 8: Secondary dendrite arm spacing (SDAS) in accordance with wall thickness

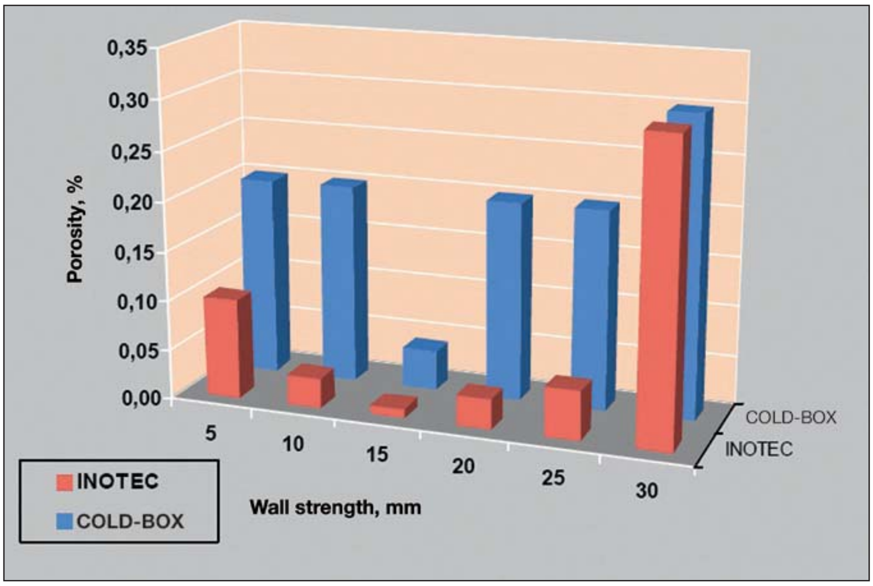

Figure 9: Porosity comparison between castings with an inserted Inotec and cold-box core

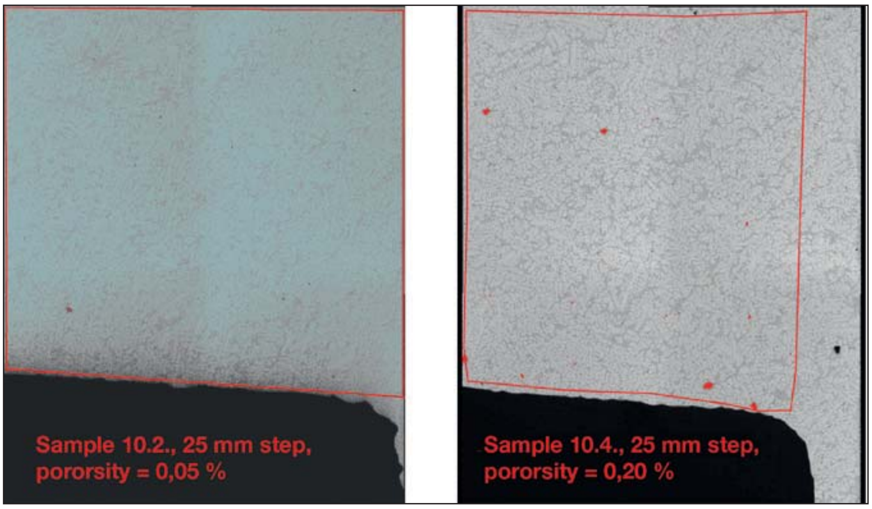

Figure 10: Porosity according to wall strength

mary solid solution of Aluminium and the (α+Si) eutectic. Furthermore, in isolated cases, the microstructure contains iron-rich precipitations in the form of Al5FeSi needles and in „Chinese script form" Al15(FeMn)3Si2. These are expected in foundry alloys. The eutectic silicon is fully modified and formed into globules by means of solution annealing during the course of the T6 heat treatment.
The secondary dendrite arm spacing (SDAS) was measured for every casting thickness: depending on the wall thickness. The SDAS is between 27 µm and 40 µm and is in the usual order of magnitude for ingot mould castings with this geometry.
The SDAS is primarily influenced by the local solidification time (SDAS = k*tE1/3 [1]), and this method is driven by Ostwald ripening. A small SDAS therefore results from fast solidification: it ensures good mechanical properties and also contributes to the modification of the eutectic silicon. The differences in the dendrite arm spacing are over the stepped section 1 µm at a maximum. This small difference is below the measurement accuracy. The results for the SADS can be regarded as identical. The slightly inferior temperature conductivity of the Inotec cores did not lead to any measurable deterioration in the secondary dendrite arm spacing **(figure 8)**.
Porosity evaluation was performed on the basis of VDG data sheet P 201 „Volume Deficits of Castings made of Nonferrous Metals" using the micrographs taken with defined 25x magnification. The images were converted to 8-bit greyscale images, and the porosity was determined by defining a threshold in grey value. Subsequently, the detected pores in the image were coloured in red and the surface area portions were evaluated in percentage terms in relation to the detection area (ROI – region of interest). The respective ROIs are to be selected here in such a mannor that they cover a maximum surface area and match the outer contour of the partial areas as near as possible.
The pore percentage in relation to the surface area is below 0.05 % on average for castings with Inotec cores, and is 0.2 % on average for castings with cold-box cores 0.2 %. In all wall thickness, the castings with cold-box cores have higher or, as in the case of the 30-mm step, at best equal porosity levels compared with the Inotec cores (figure 9). The volume deficits are chiefly to be regarded as gas pores mainly originating from the outgasing of the core and not from the gas content of the melt **(figure 10)**.

Elongation

For tensile tests, tensile samples were prepared from each step of the cast-in variant and centrally from the fully enclosed variant in accordance with DIN 50125 – B8x40 and B4x20 (for the step with a wall thickness of 5 mm), and the 0.2 % elongation limit Rp0.2%, tensile strength Rm and fracture elongation A were determined in the subsequent tensile test in accordance with EN 10002-1 on a universal testing machine.
For all samples, the results for the tensile strength, elongation limit and fracture elongation are above the minimum values defined in standard EN 1706:1998 for test specimens taken from a casting.
If the results are compared as overall means across all steps a slightly greater tensile strength and a significantly greater elongation are apparent in the case of the open cores. The yield strength was almost the same for the castings with the Inotec cores **(figure 11)**.
The results for the fully enclosed cores display the same trend, i. e. a greater fracture elongation and ultimate tensile strength for the Inotec core **(figure 12)**. Overall the values are rather lower than for the fully enclosed cores for the samples taken from the thick-walled area. The impact of the porosity on the mechanical properties is clearly shown in **figure 13**. The tensile samples were

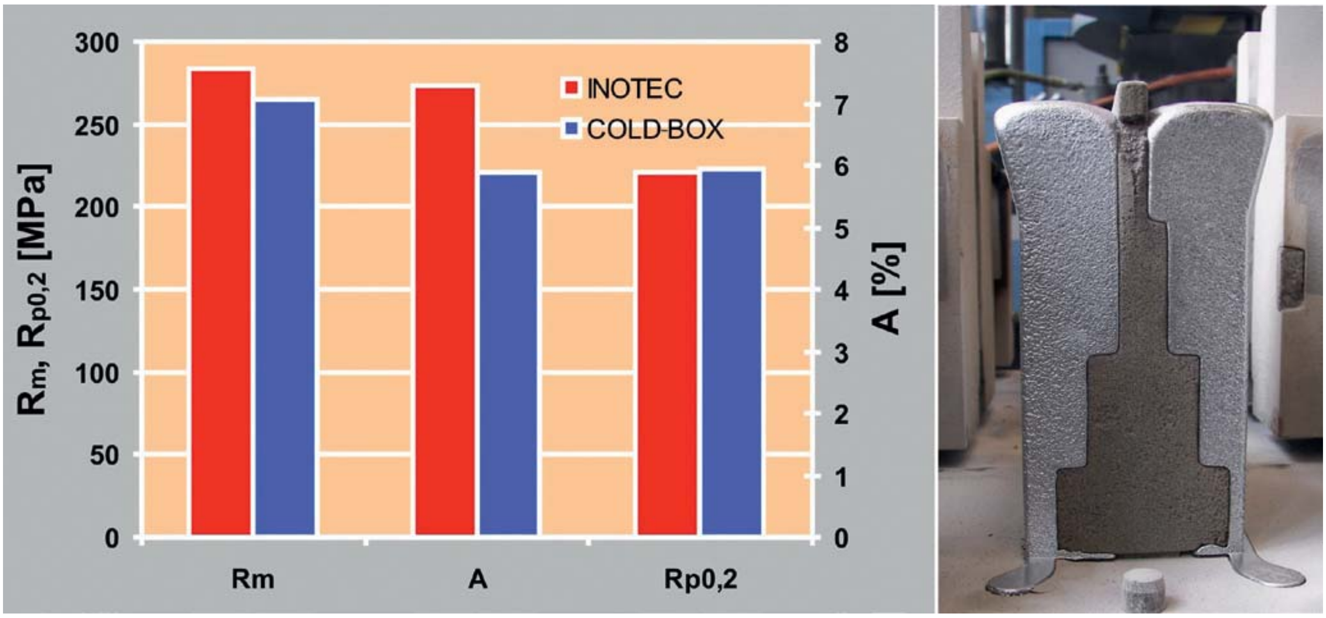

Figure 11: Results of the tensile test for cores with a free surface to air

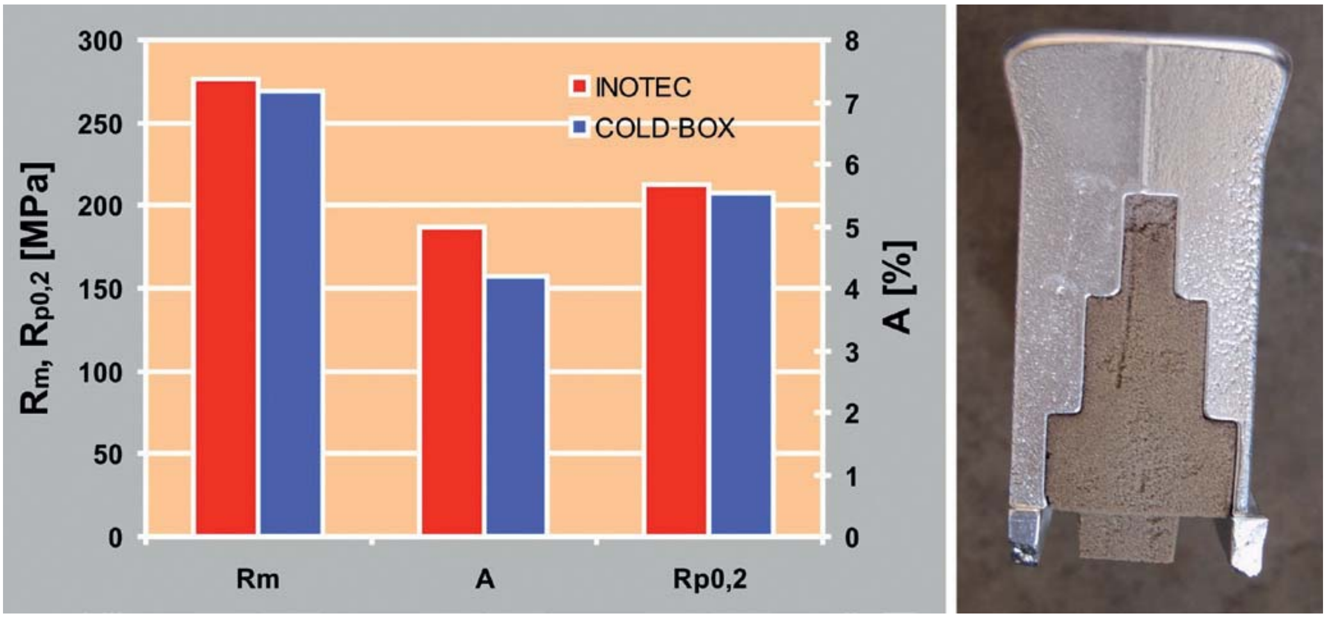

Figure 12: Results of the tensile test for fully enclosed cores

taken from the same casting, one from the Inotec side and one from the cold-box side. In the linear-elastic region, the stress-strain curves are identical. Under plastic strain, the curves show equivalent pattern up to the rupture of the sample from the casting with an inserted cold-box core. Because of the lower porosity, the Inotec sample achieves a significantly greater fracture elongation and, as a result of increased work hardening, also greater tensile strength.

Advantages for the Calculation and Design of Castings

From the castings of the dual-step plate ingot die, 20 rotating bending samples were prepared from the Inotec and 20 from the cold-box casting side. In the subsequent dynamic fatigue test according to DIN 50113 at room temperature, the Wöhler curve (S/N curve) for an ultimate number of cycles of 5*107 was determined with a frequency of 200 Hz and a stress ratio of R = -1.

Failure probabilities for 10, 50 and 90 % were calculated via a log-normal distribution. The variance T is obtained from the ratio of the values for 90 % and 10 % failure probability.

For the 50% failure probability, the evaluation **(figure 14)** shows a 3 MPa greater dynamic strength for the samples from the castings with the Inotec cores. Moreover the difference in variance is striking. As a result of the very even casting quality, the variance of the Inotec samples is significantly lower, whereas the results for the cold-box samples clearly depend on the porosity. Samples with less porosity attain almost identical values to the Inotec samples and in samples with greater porosity, the dynamic strength declines considerably.

In consequence this large variation requires larger safety margins and this must be must be taken into account in the design of components. Therefore, a higher safety factor is required: Thus castings have to become more bulky, heavier

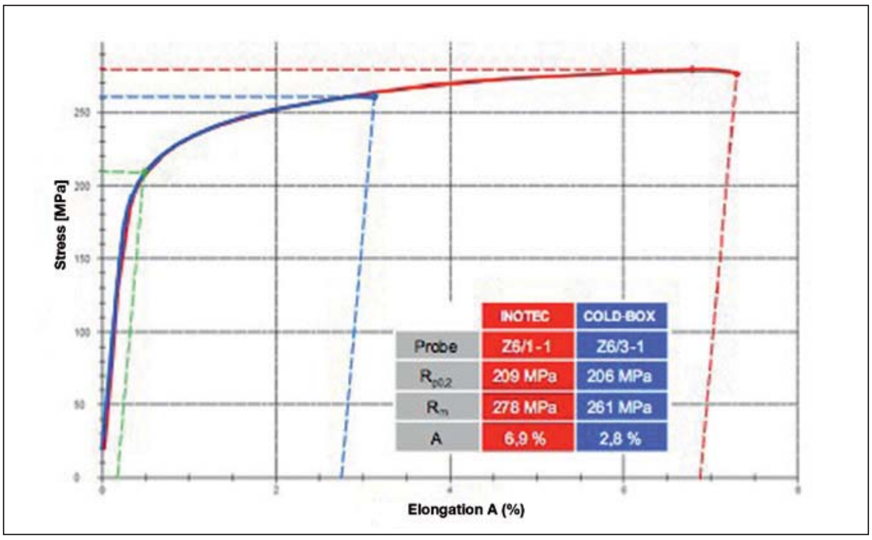

Figure 13: Comparison of the stress-strain curves between castings with an inserted Inotec and cold-box core

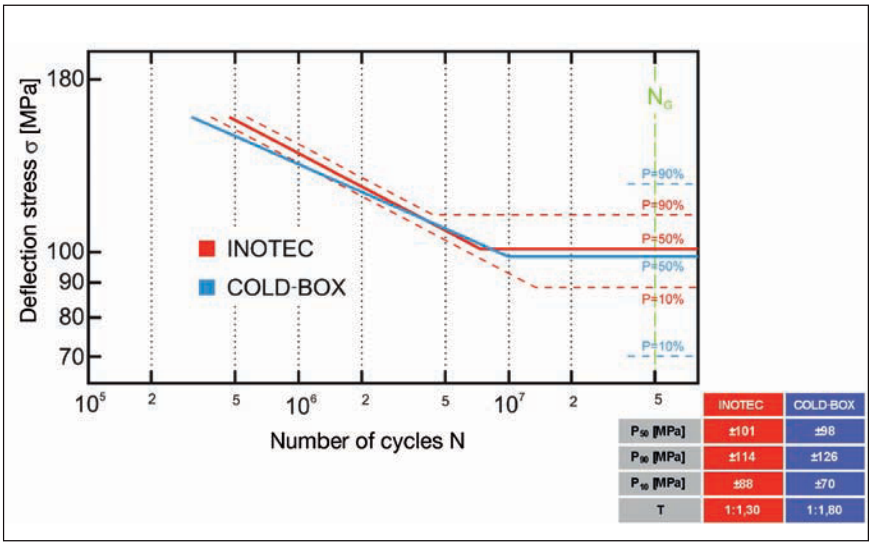

Figure 14: S-N Wöhler curves for different failure probabilities (rotational bending fatigue test)

and expensive to accommodate larger variation during processing with cold-box cores.

Summary

The strong emissions of the cold-box cores were clearly visible during casting. The emissions of the Inotec core are significantly lower, and virtually no impairment of the surroundings due to fumes and/or odour was observed.

It was also noticeable that a resin layer of organic condensates was formed on the die half in which the cold-box cores were inserted after only a few castings. In contrast, the die half with the inserted Inotec cores had only minor deposits after the same number of castings. This results in more cleaning work for the die and higher cleaning costs for castings with cold-box cores.

In all wall thicknesses, the castings with Inotec cores have significantly lower or at worst identical porosity levels compared to those with cold-box cores. The volume deficits are chiefly to be regarded as gas pores originating from core gases. Overall, the pore percentage in relation to the surface area is to be regarded as low for all castings, and because of the good melt quality, it can be assumed that the porosities are only caused by core gases.

The results for the secondary dendrite arm spacing (SADS) for castings with different cores can be regarded as identical. The slightly inferior temperature conductivity of the Inotec cores did not lead to any measurable increase in the secondary dendrite arm spacing.

In the cast-in and fully enclosed case, the elongation and tensile strength for the castings with inserted Inotec cores are greater than with the cold-box variants, whilst the elongation limits are roughly equal.

For the castings with Inotec cores, the dynamic strength is marginal elevated in comparison to that with cold-box cores. The variance of the Inotec samples was significantly lower as a result of the more uniform casting quality. Consequently in future, there are significant advantages for the design of castings using Inotec core technology.

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Further information:
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Literature

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