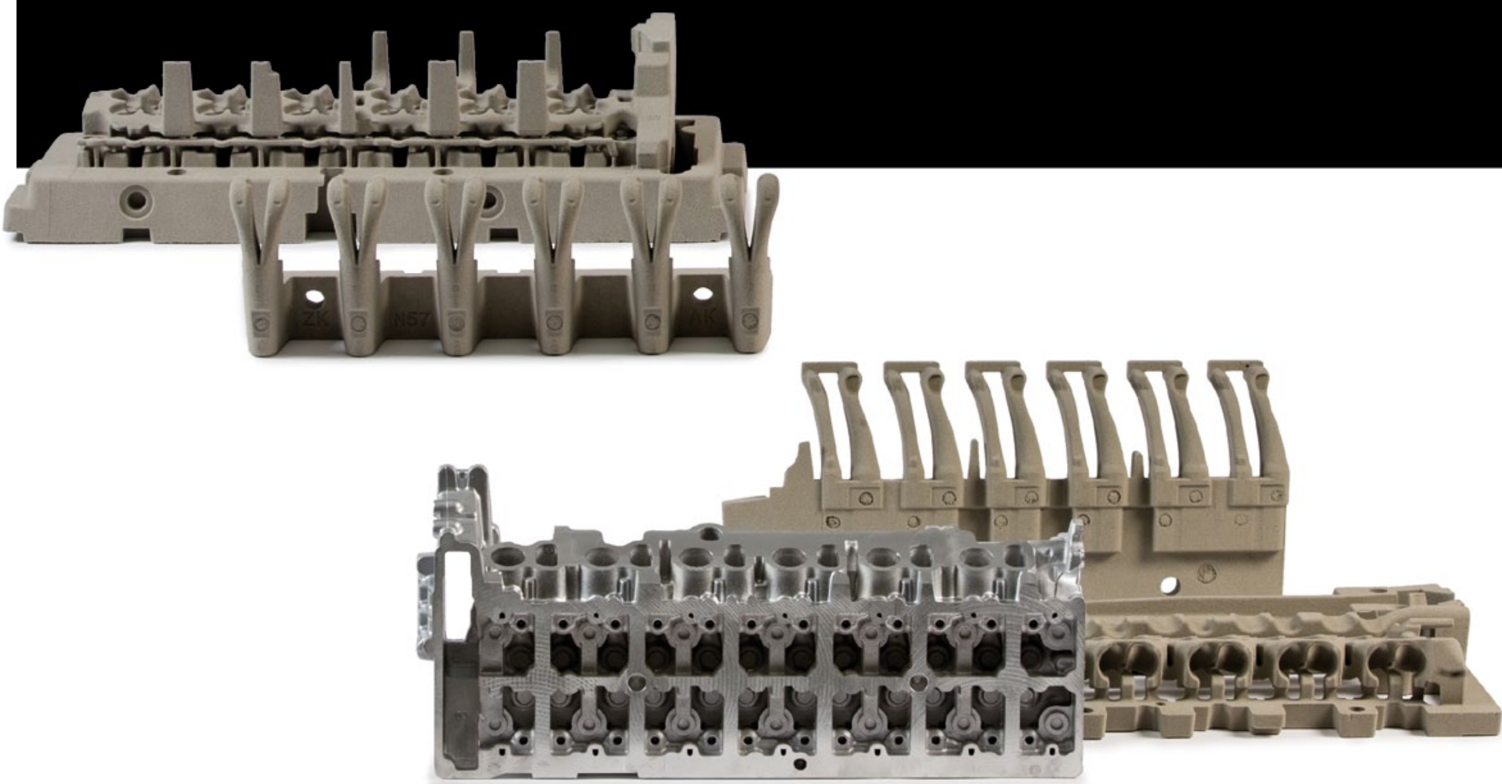
TOMORROW'S CYLINDER HEAD PRODUCTION
ECOLOGY, ECONOMY AND MATERIAL ENHANCEMENT BROUGHT IN LINE



BMW presently runs the first emission-free foundry worldwide in the company's Landshut plant with the production of shaping sand cores. In tight cooperation with ASK Chemicals, BMW Light-Metal Foundry changed over the core production from customary organic binders ("the glue for the sand") to the environmentally-friendly inorganic binder system Inotec.

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INTRODUCTION

Such inorganic binders basically consist of silica sand dissolved in water, which means that hazardous emissions are next to none. Apart from the environmental aspect, the innovative process offers significant advantages with respect to component strength which is considered the main engine feature as well as to quality and costs. This article both highlights the chemical background of the sand core manufacture as well as the advantages for the casting process.

Presently, the inorganic core manufacture is one of the greatest challenges for the foundry industry. Beside the positive impact on strength properties, quality and costs, it is the potentials especially concerning sustainable and environmentally compatible production that will demand the change-over from sand core manufacturing to die casting in the next years.

Since BMW Group is playing a pioneering role in implementing both efficient dynamics with every vehicle as well as efficient environmental protection (see also BMW Sustainable Value Report 2010 [1]), the casting production with inorganic bonded sand cores represents an important contribution to the strategy of sustainability. BMW Light-Metal Foundry picked up this relevant issue in 2005 and initiated a development partnership with ASK Chemicals [2, 3]. The complex development and conversion scenario in full operation, also called "brown field approach" is completed by now [4,5]. Only inorganic sand cores are being employed in the current die series production. Until now, approximately 7 million sand cores have been blown, and approximately 2 million casting pieces have been produced – among which a total of approximately 1 million cylinder heads, whilst having saved 4000 t of CO_2.

Among all engine components, the cylinder head is by far the most crucial one in respect of properties concerning the functional behavior, thus setting extremely high demands for the casters. The constructional goal is to combine as many features as possible in the most confined space while simultaneously maintaining the basic physical properties such as durability and material strength. The following casting processes are nowadays popular in foundries:

: die casting
: lost Foam Process
: sand casting
: high-pressure die casting.

Almost 90 % of all cylinder heads in Europe are being produced with die casting. During this process, the outer contours of the casting are modeled by permanent molds (so-called dies). The inner contours of a cylinder head, such as water jacket, gas exchange and oil channels as well as possibly other integrated functions or channels are modeled by sand cores. The sand cores are positioned into the die immediately prior to pouring – either individually or assembled to a core packet. Since the construction is becoming increasingly compact with filigreed channels and a substantially reduced wall thickness all over the cylinder head, the sand core production is often enough considered the most complex task within the casting process.

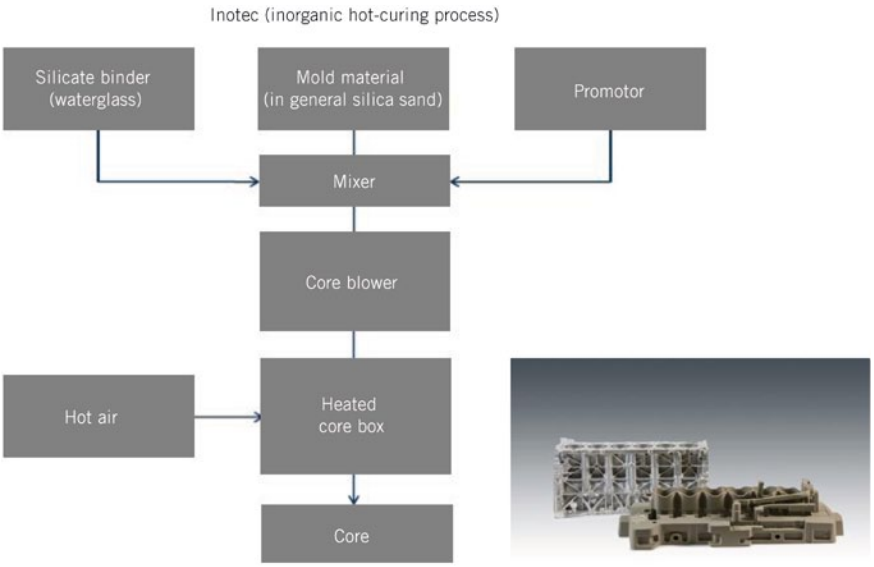
CORE MAKING

In order to yield absolutely sand-free casting pieces for further processing, during core making, especially for cylinder heads, it must be ensured that both mold material and binder system can provide:

: excellent dimensional accuracy
: clean and smooth surface
: superior thermal stability
: good shakeout (binder collapsibility).

The classical binder is generally a phenol resin which is mixed together with the poly isocyanate and the mold material (silica sand). The ready mixed sand is then virtually "blown" inside the core making machine under high pressure into the core box. The curing is done with a tertiary amine catalyst, which is very powerful und takes just a couple of seconds. The whole core making process can be realized in less than a minute. The cores can be handled immediately after the process, i.e. assembled into core packages and positioned into the die. Binder amounts for aluminum casting typically range about 0.6 weight% per component.

This core making process, however, is known for the negative aspect of amine emissions, especially during unfavorable manufacturing conditions. If the chemical components come into contact with the hot metal during pouring, BTX emissions, CO and CO_2 are likely to develop during



❶ Description of Inotec core making process sequence

combustion. After pouring, the mold material is reconditioned either mechanically or thermally [6] and re-inserted into the core making process and recycled.

REQUIREMENTS FOR THE INOTEC PROCESS & CHEMICAL BACKGROUND

A large number of system properties have been a significant challenge for the development of a novel, environmentally-friendly binder with the following features:

- good flowability of the core sand mixture
- good strength level immediately after core manufacture
- superior hot strength of the cores
- good storage stability
- productivity comparable to the customary core making processes – if not improved
- recyclability of the core sand
- odorless during core production and pouring
- no harmful gasses during core production and pouring
- good shake-out after pouring
- no condensate formation on the die.

Inotec is a binder on silicate basis, which in simple words is nothing but silica sand dissolved in water. It has some affinity to the waterglasses employed in the sodium silicate (CO_2) process. Contrary to the CO_2 process, however, the curing is not entirely a product of chemical reaction but rather a combination of physical drying process and chemical reaction. This is the reason why the Inotec process requires heated tools. The tool temperature (150 to 200 °C) not only drives the water (solvent for the silicates) out of the core but also initiates a chemical reaction which leads to a cross linking of the silicate molecules. Water is again formed as a by-product of the cross-linking. Chemically, this process is called condensation reaction, which means that two molecules bond, while simultaneously separating a smaller molecule, i.e. water in this case. During curing, water is released from two different sources (solvent + reaction by-product). Ideally, this chemical-physical curing process is favored by hot purge air (approximately 150 °C) in order to reduce the cycle times during core making and to make sure that the moisture is driven from the core to a 100 %, ❶. The residual moisture remains in the core and becomes visible as water vapor during pouring.

The curing reaction is in part reversible (balance reaction). This means that energy and water (i.e. elevated temperatures and high ambient moisture) are able to initiate a reverse reaction which eventually dissolves the cross-link of the silicates. In consequence, the cores lose strength and break.

This can be avoided by removing the water component out of this balance, i.e. by storing the cores in a dry environment. Since this is not always easy in practical operation, additives are used to substantially decelerate this reverse reaction and to allow for a process reliable core handling even following “regular” storage.

ADVANTAGES OF THE INORGANIC BINDER SYSTEM INOTEC

❷ shows the pouring of a cylinder head modeled with organic sand cores. Both the smoke and the typical foundry smell developing in the process are combustion products deriving from the incineration of organic binders contained in the sand

❷ Core gas developing during casting a cylinder head made with organically bonded cores

❸ Combustion residues (condensate) during a lab casting test (left: conventional organic binder; right: new inorganic process)

cores. The result of an equivalent test tube trial, ❸, is shown left for the organic binder and right for the environmentally-friendly inorganic binder. Both variants of bonded sand are each heated up in the respective test tube until reaching pouring temperature.

The organic smoke (exhaust fume) condenses on the test tube wall, leading to a visible color change. The test tube on the right (with the inorganic binder) does not show any signs of condensation even after having been heated up to pouring temperature. The organic smoke and condensate formation has a negative impact on many factors, such as:

- working conditions for the employees
- component strength
- cycle time
- equipment and tool service life as well as
- purification of exhaust air and the resulting consumption of energy.

ADVANTAGES FOR THE EMPLOYEES

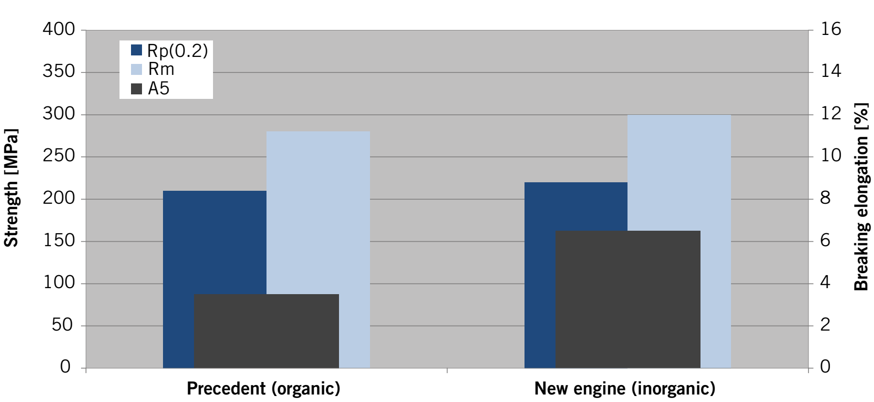
The omission of amine catalysts during core making and the absence of smoke during pouring provide for an improved working environment with substantially reduced odor development. When casting takes place with organically bonded sand cores, condensate precipitation (combustion residues) on the tools is often the cause, which has to be eliminated regularly by means of CO_2 blasting with dry ice. The physical strain for the workers dealing with the hot dies is quite high, not to mention the high degree of noise pollution in this area. Casting with inorganically bonded cores reduces this intensely costly and energy-consuming cleaning procedure by more than 75 %, and the noise, of course, too. Another advantage is the omission of expensive exhaust air system cleaning, and the use of hazardous materials, e.g. peroxide, in waste air purification plants is no longer necessary.

ADVANTAGES FOR COMPONENT STRENGTH AND LIGHT-WEIGHTING POTENTIAL

The combustion byproducts of the core binders getting in contact with the hot aluminum in the mold cavity (the die) are not only harmful to the workers involved, but also to the process as a whole. Similar to moisture precipitations on windows during winter, reaction products in the form of condensate are to be found in the tools as well as in the extraction and hall venting systems. The lower the ambient, i.e. the tool temperature, the higher the condensate pollution. By implementing the inorganic core manufacture in the Light-Metal Foundry of BMW Group in Landshut, it has become possible to realize accelerated solidification speeds (up to – 20 %) with significantly cooler casting tools (< 100 °C instead of > 200 °C), whilst improving the component strength (reduced dendrite arm spacing) and simultaneously lowering the cycle times under the aspect of cost efficiency. ❹ shows a comparison between the component strength obtained for the new cylinder head of the BMW six-cylinder in-line engine [7, 8]. The improved component strength is of vital importance for the development of new fuel efficient and highly supercharged engines with higher ignition pressure and higher power density.

ENERGY CONSUMPTION, CO_2 AND COST ADVANTAGES

With reference to a comparative evaluation of inorganic and customary organic

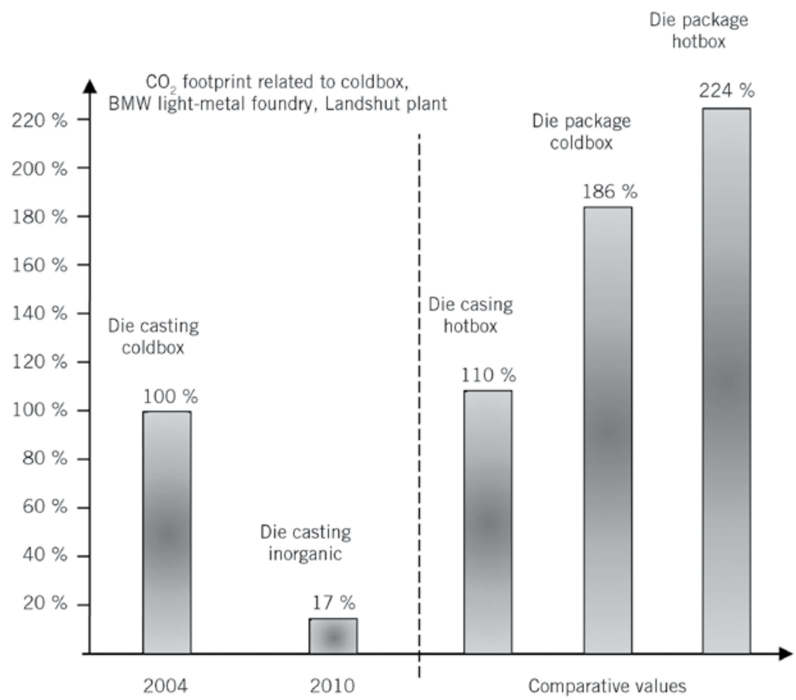


❹ Strength levels in comparison; casting results with conventional organic binder system vs. new cylinder head for R6 in-line Diesel engine made with inorganic binder systems binder systems in foundry operation, it is essential to view the whole process chain. The higher capital expenditure in the core shop will be compensated for in the process chain. As compared to the currently used core making methods, the manufacturing costs focus at a comparable level [5, 6], whereas the core box maintenance costs are getting lower due to less dirt. This guarantees higher efficiency during casting. The total absence of organic components also provides two decisive advantages for the components during pouring and cooling: significantly prolonged cleaning intervals and shorter cycle times.

The main optimization potentials in the casting process given by the use of inorganically bonded sand cores are:

: cycle time: - 15 %
: productivity: + 15 %
: tool maintenance: - 50 %
: tool service life: + 25 %.

Apart from the cost saving potentials, also the reduced energy consumption plays an important role. Cleaning requirements are drastically reduced, and the dry ice demand shrinks to a minimum. Cost cutting becomes most effective, though, in the area of the waste air extraction system. Until recently, the aluminum foundry of BMW Group in Landshut has been paying a natural gas bill over 400,000 Euros per year for waste air treatment (thermal afterburners). With the complete conversion to inorganic core making, this matter of expense as well as the CO_2 equivalent, have become a thing of the past. ❺ shows the CO_2 equivalents of different core making processes.



❺ Comparison of CO_2 consumption with various casting and core making processes

PROSPECTS

The conversion of the core shop to inorganic binder systems has brought about completely new potentials regarding component strength, sustainable manufacture, productivity and component quality. Process-inherent cutbacks referring to the die casting layout may now be reconsidered. Especially for high-performance engine key components such as cylinder heads and crank cases, the casting technique now provides additional potentials for improved strength which is a relevant contribution towards downsizing. Thus, “BMW Clean Production” forms the technical basis for “BMW Efficient Dynamics”. This means a vast improvement of working conditions inside the plant and of living conditions for the residents as well. A new ecologically and economically improved state of technology has been already defined. As far as highly developed countries with stringent environmental regulations are concerned, this favorable development also provides competitive advantages and will be sooner or later part and parcel of environmental legislation.

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