New coating concepts for highly complex engine blocks

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Introduction

In response to the global requirement to reduce pollutant emissions from motor vehicles, the overall trend has been towards the manufacture of smaller yet more powerful combustion engines. This tendency has been known as “downsizing” for more than 10 years.

The target is to reduce consumption and emissions, particularly of CO₂. In future, European car manufacturers will not only keep CO₂ emissions of an engine under close scrutiny, the carbon footprint of the car throughout its lifetime will be a critical feature.

CO₂ emissions can be reduced if less fuel is consumed by the engine. This is possible in two ways. One – as mentioned above – is by replacing large-capacity engines by smaller and less fuel consuming engines with the same output. Another possibility is to reduce the total weight of a vehicle.

To keep the weight reduction effort at a minimum, it makes sense to pick a large part with high weight saving potential. Normally the engine block is the heaviest individual casting in a car. The weight of an engine block can be reduced by making the walls thinner. A “thin-wall concept” can save up to 60 percent wall material.

Figure 1: Weight reduction of a finished thin-wall part made with the core packaging process

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Further weight reduction can be achieved if functions in the engine block are combined. By integrating chain cases, pressure oil lines, oil return lines, blow-by and water ducts the number of components and therefore the total weight of the drive assembly can be reduced. A positive side effect is a higher robustness of the whole engine.iii

Manufacture with the core block or core package process

Modern engine blocks are extremely complex, therefore new approaches are required in order to manufacture them. Today, complex, thin-walled castings are made by means of the core block or core package casting method in an upright pouring position.3,iv

The advantages of this method are obvious:

- High dimensional stability (wall thickness +/- 0.5 mm)
- Controlled mould filling behaviour
- Improved core gas venting
- Complex perimeter geometries are possible
- Additional outer and side cores as well as the cores for the supply ducts increase the core volume and therefore also the consumption of binder and coating compound.
- More cores are needed when many functions are combined inside the engine block. Particularly the supply ducts require delicate and highly complex cores7.

This leads to new requirements for core binders and, in particular, for the coating material and its composition.
Gas defects

Despite improved gas venting from a core package in vertical pouring position\textsuperscript{7} complex delicate cores are particularly prone to casting defects due to gas when the core geometry is very thin. Figures 4 and 5 illustrate defects caused by gas at the base of the water jacket core. The authors believe that the main reason why such defects occur is the gas pressure that builds up in the core at a certain point in time during the casting process. If the gas pressure exceeds the metallostatic pressure of the melt, gas can enter the melt increasing the risk of blow hole formation. In addition, high pressure in the core can cause the removal of the coating from the core. This leads to the formation of gas pressure scabs.
**Measurement of gas pressure**

Gas pressures in cores are measured in the authors’ pilot plant. The cores are immersed in molten metal at a constant temperature; a sensor measures the pressure for as long as the core remains immersed. The cylindrical sample core is 220 mm long and is immersed into the molten iron to a depth of 190 mm. Two “gas pressure cores” of different diameter are illustrated in Figure 6 – before immersion (left) and after immersion (right).

![Figure 6: Gas pressure measurement with 20 mm and 30 mm core diameters](image)

The gas pressure in a given core mainly depends on the type of sand, the binder, the binder proportion and the applied coating layer.

Looking at the gas pressure curve of coated cores (Figure 7) it is obvious that gas pressure starts building up as soon as the core is immersed in the melt (approx. 2.5 s after measurement starts). The further the decomposition of the core binder progresses, the higher the gas pressure rises. In this example, the maximum gas pressure is obtained after approx. 35 s, after which the gas pressure drops. Only some remaining binder decomposes.
Coats permeable to gas

One way of reducing the gas pressure build-up in the core is by using gas-permeable coating material. Figure 8 illustrates that when the coating is permeable to gas the gas pressure in the coat can be reduced substantially. Modern coating materials allow permeation of the gas only during first contact with the melt so that initially high pressure can build in the core. During longer impact of the heat load the coats sinter and the gas permeability deteriorates.

The designer of coating materials for core packages with delicate thin cores must also consider that the gas pressure builds very much faster in thin cores and thin core sections than it does in thick cores. Besides, the small cross section does not allow the gas to vent quickly enough
through the moulding material. Thus, the gas pressure is much higher there. Figure 9 illustrates the difference between a core with 30 mm and another core with 20 mm diameter. The shift of the maximum gas pressure is about 12 s in this example.

Figure 9: Gas pressure measurement with different gas geometries

This shift can also be observed in coated cores (Figure 10, blue and green curves). Gas pressures of approximately 130 mbar were measured in coated 20-mm cores. The pressure is so high that the gases cannot escape through the core alone. Larger gas volumes find their way into the melt. As a result of this, the melt "boils". Depending on the geometry and position of the core in the core package, these two effects increase the risk of gas defects (see Figures 9 and 10).

Figure 10: Gas pressure curves with different geometries (20 mm and 30 mm) and two coating materials
Coating materials with controlled gas permeability

As can be seen in Figure 7, when Cold Box binders with some silicate (SIPURID) are used, the gas pressure can be reduced for the whole time of exposure to the thermal load. Then again, one result of the higher gas permeability of the coating material is that the gas pressure in the core drops (Figure 9). With thin cores, this effect can only be seen when the gas pressure in the core does not rise high enough to substantially exceed the metallostatic counterpressure (Figure 10).

When gas escapes through the melt, i.e., when the melt “boils”, this always entails the risk of gas defects. Modern coating systems can delay the gas pressure build-up and postpone the maximum gas pressure as much as possible (cf. coating material A and coating material B in Figure 10). If the metal solidifies earlier and a frozen shell forms at the core, no gas can escape through the melt.

Modern coating materials must meet the following requirements to avoid gas defects during the core block process:

- High gas permeability during initial contact with the molten metal,
- High (insulating) action to avoid rapid pressure rise with coat thicknesses of as little as 250-300 µm,
- Low gas permeability during extended contact with the melt.

These materials, for which Hüttenes-Albertus GmbH has filed a patent application\(^v\), are known as “coating materials with controlled gas permeability”\(^vi\). The sintering properties of these modern coating materials feature what is called “thermoflexible behaviour”, i.e., the flexibility of these coating materials increases under exposure to the heat of pouring. Sand expansion defects, for example, can be covered effectively even with thin coats; veining and other defects can be avoided.

No residual contamination

If the reactivity of the constituents in the coating material to the melt is low, the sintering behaviour ensures very good peeling of the coat from the casting. This is a precondition for avoiding residual contamination in the narrow and difficult to access supply ducts in the blocks. This is a challenge to the caster\(^5\) and therefore also to the producer of the coating material.
The segment of a so-called veining block in Figure 11 illustrates this effect clearly. When emptied, a black coating layer is left on the core side of the casting. The coating layer does not stick but large patches of it come off the casting due to high internal stress.

Figure 12 also illustrates clearly that the sintered layer has come off the surface of the casting. These parting properties of the thermoflexible layers with little reactivity are not successful in all cases. The coating layer can be held back by the sand in narrow ducts. This layer is very difficult to remove by blasting. Figure 13 shows a test core with a 2.7-mm web and a section through the casting to which it belongs. The coating material comes off the casting surface well in the 5.7-mm wide section but some sand and coating material remains in the duct that is 2.7 mm thinner. If that duct were inaccessible to blasting, undesirable residual contamination would remain there.
As can be seen in Figure 14, solutions to this problem have been found. However, more development effort is needed to further reduce residual contamination in high-complexity engine blocks.

**Summary**

To approach the ideal carbon footprint for future generations of motor vehicles, it will be necessary to reduce the weight of heavy components. Thin-walled engine blocks can save 60 percent of the wall materials. By combining functions further weight reduction is achieved but the number of cores increases. Integrating supply ducts, in particular, requires extremely delicate and highly complex cores. Engine blocks are therefore produced by the core block or core package method with vertical pouring. This leads to new requirements for core binders and particularly for the coating materials and their compositions.

Despite improvements in gas venting, gas causes casting defects (scabs, blow holes) in complex cores with slim core geometries. Modern gas-permeable coating materials reduce the gas pressure in the core. They are permeable to gas during the initial contact with the melt so that no high gas pressure can build up in the core at the beginning. As the thermal exposure continues, these coats sinter and their gas permeability dwindles. Modern “coating materials with controlled gas permeability” can delay the gas pressure build-up and postpone the maximum gas pressure as much as possible. A patent application has been filed for these materials by Hüttenes-Albertus GmbH. Along with the sintering properties of these coating materials, they exhibit “thermoflexible behaviour”: The coatings become more flexible under the action of the pouring heat. Sand expansion defects can be covered effectively even with thin coating layers; veining and other defects can be avoided. Another effect of the sintering behaviour is that the coating peels off the casting surfaces well provided the reactivity of the components of the coating materials with the melt is low. This property is also a precondition for avoiding residual contamination in narrow and difficult to access supply ducts of the blocks. The parting properties of the thermoflexible layers with low reactivity are not successful in all cases: The coating layer can be held back by the sand in narrow ducts. More development effort is needed to further reduce residual contamination in high-complexity engine blocks.
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\[1\] T. Martin, R. Weber, R.-W. Kaiser, Dünnwandige Zylinderblöcke aus Gusseisen, Gießerei-Erfahrungsaustausch 08/2003 357
\[2\] T. Martin, R. Weber, R.-W. Kaiser, Dünnwandige Zylinderblöcke aus Gußeisen, Gießerei-Praxis 4/2003 143
\[3\] MTZ 05/2007 2.
\[5\] See patent application by Hüttenes-Albertus GmbH: PCT/EP 2010/055306
\[6\] See patent application by Hüttenes-Albertus GmbH: PCT/EP 2010/055306