Pouring into molding sand without organic additives and without cores – no fumes are visible (Photos: S & B)

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Challenges of introducing inorganic mold and core making processes

The future of the foundry industry depends on the availability of products and processes that enable the production of high-quality castings. These castings will have to meet customer requirements and, at the same time, make a contribution to reducing environmental pollution and improving working conditions. This technical article provides an overview of materials for high-grade casting production that also have a positive effect on the environment

To understand where emissions may arise in a foundry during pouring, cooling and knocking out (PCK), CERP (Casting Emission Reduction Programme), based in the USA, set up an emission profile. This profile provides an overview of sources of HAP (Hazardous Air Pollutants) in an iron foundry. 90 % of HAP emissions arise during pouring, cooling and knocking out. These emissions are often difficult to quantify due to the very different conditions prevailing in casting shops. Therefore a special CERP casting shop was developed enabling the different PCK sources to be collected and exactly measured (**Figure 1**).

To obtain a basic understanding of the emission sources, it is recommended to first describe the emission potentials of the materials and substances involved. **Figure 2** shows that a defined amount of cast metal has a specific emission potential.

Although emissions also arise from core making processes, especially when organic binders are used, these emissions are not dealt with in this article.

The two main sources of emissions during casting are the molding sands and the cores. The volume of the mold sand (500 kg) is much larger than the volume of the core sand (20 kg). Emissions are caused by disintegrating organic additions, such as lustrous carbon forming agents accounting for 0.25 % per cycle, core binding agents accounting for 1.4 % and core sand additives (wood flour) accounting for 1.0 %. These three emission sources together have an emission potential of 960 g VOC (volatile components), with 460 g coming from the cores and 500 g from the molding sand. This equals 48 % of the emission potential being accounted for by core making and 52% by mold making. The calculation basis in figure 2 can also be used to represent modifications and improvements.

The foundry of the future has different options. Some refer to the mold and core making processes, others to the selection of newly available binders and other consumables. To fully exploit the advantages of new materials, the development should be geared towards processes tailored to these materials. Productivity, security of production and, last but not least, the casting quality must be considered when changing processes with a view to reducing or eliminating emissions during pouring, cooling and knocking out.

The future of the foundry industry is closely linked with the use of bentonite-bonded molds and the cores used with these molds. This technology is highly productive and less polluting, as the molding material can be reused and regenerated. Some new materials have already been introduced in this area. The gained experience serves as the basis for further developments.

Greensand (bentonite-bonded molding material)

Some greensand foundries reduced the amount of lustrous carbon forming agents by replacing them by emission-free, inorganic additions. This has had no effect on the casting quality. At the same time, the use of inorganic binders (water glass) in core making has been attracting great interest. The fact that inorganic binders do not cause any emissions also provides the basis for a clean foundry, with the additional benefit of reducing the number of off-gas treatments.

The inorganic binder system also includes inorganic additives used to improve the casting surface, the flow characteristics, mold strengths or knocking-out properties.

Especially such complex processes as greensand systems call for the new materials to be gradually introduced in a foundry, applying a multi-step method. This approach guarantees a smooth transition, providing enough time to establish an adequate process and casting control that also permits optimizations. The complete transition to a greensand system should take approx. one year (**Figure 3**).

Different positive effects following the introduction of inorganic additives were determined at a greensand

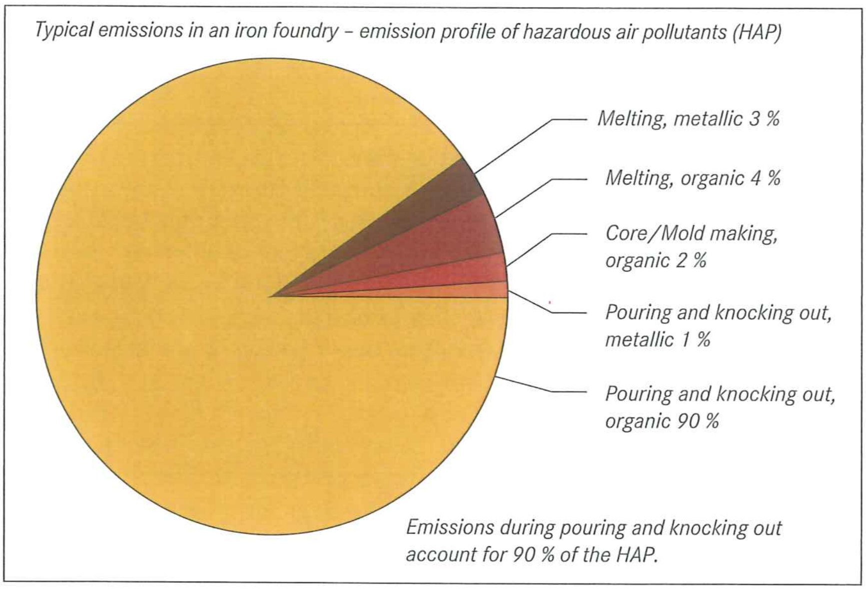

Figure 1: Investigations by CERP show that 90 % of the hazardous, air-contaminating substances come from the greensand and the cores.

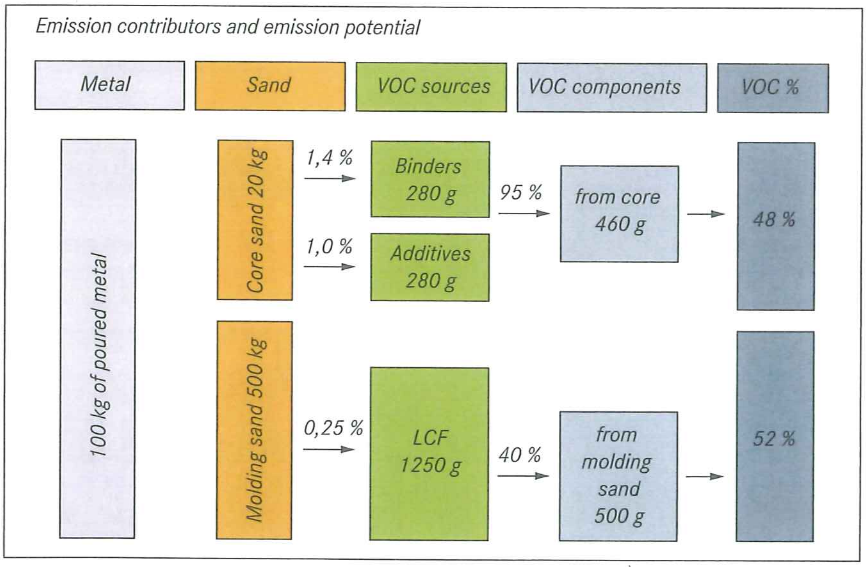

Figure 2: The emission potential can be calculated from the input materials. This is a worst-case scenario showing the maximum possible percentages of volatile components (VOC). If new substances with lower contents of volatile matter are used, the quantitative changes can be indicated in a new slide.

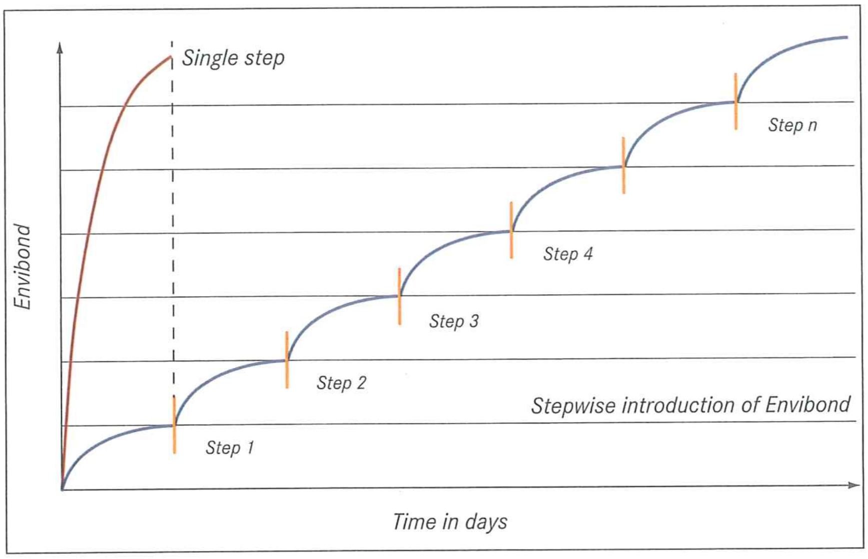

Figure 3: The pace at which the transition takes place depends on the percentage (%) of the entire, new component, assuming a constant volume (input = output). At a rate of 3 to 5 %, this "refreshment" (by the product Envibond) is almost linear in the initial phase. The process becomes slower with time as a result of more of the "old" substance leaving the system. By introducing the new product stepwise, for example, via a second silo or modified recipes, it is possible to have an almost linear transition over a period of one or two years.

production line. The most important effects were the reduction to zero of fumes arising during pouring (Figure on page 10) and the reduction in CO at the work place from approx. 40 ppm down to 15 ppm (**Figure 4**).

At the same time, loss on ignition decreased from 4 % to 2.3 % (**Figure 5**). The loss on ignition of 2.3 % results from the remaining lustrous carbon forming agents used, the binder residues existing in the system and the water of bentonite crystallization. Pilot casting tests (**Figure 6**) and tests under operating conditions were conducted to characterize the emissions from greensand. Measurements of the benzene, toluene and xylene contents and of the gas volumes during the pilot tests showed that, after introducing inorganic greensand additives, benzene emissions decreased from 206 mg/kg of molding material to 129 mg/kg. It is to be noted here that these measurements represent a worst case scenario, because the complete specimen is heated up to 900–1,200 °C and the arising gases are not adsorbed by the surrounding mold. The measurements in the foundry under operating conditions during pouring, cooling and knocking out showed similar reductions in emissions after replacing 70 % of the coal (lustrous carbon forming agents). These measurements were made under the same process parameters, i.e. the same casting program without core sand dilution. Odour nuisance, given in odour units (OU), during knocking out was also lower. However, these values should be considered as indicative due to the accuracy of the measurement. Also without this measurement, it can be easily seen in the pilot plant that fume and condensate development is low when inorganic greensand additives are used. It can be expected that as a result of the reduced volume of gases, especially, of the lower gas peak, there will be fewer gas-caused defects in the castings.

An important task to control the properties of the molding sand by means of suitable analyses, both during and after the multi-step transition. A preferred procedure is to measure the corresponding specimens from both molding sand systems in parallel. This reveals that the molding material properties do not change sig-

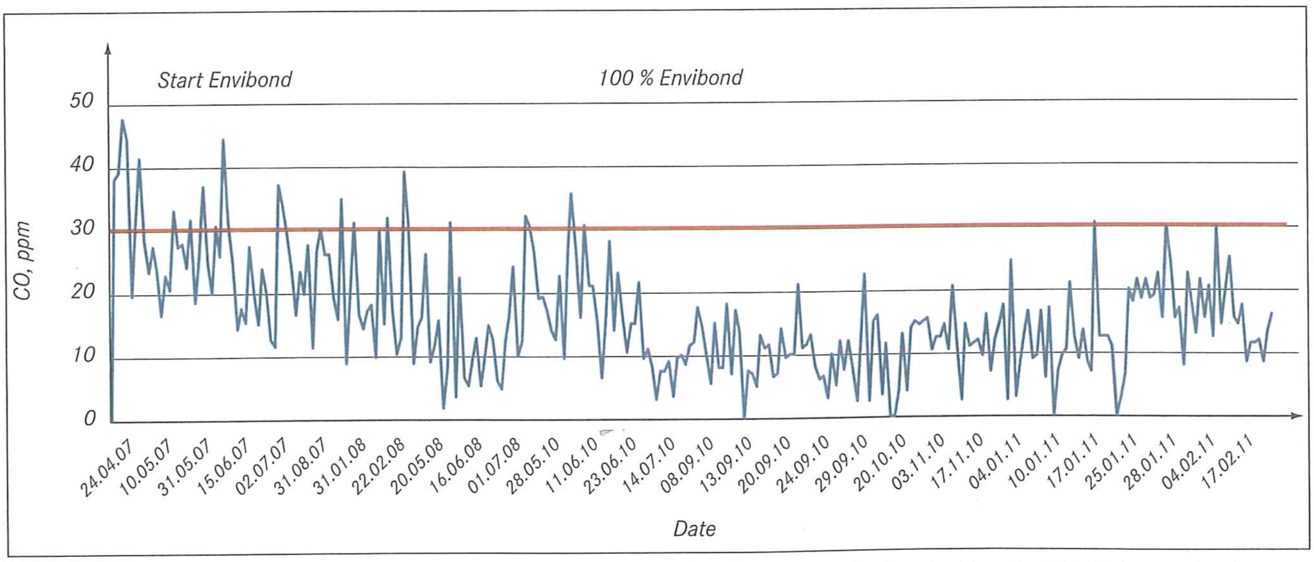

Figure 4: Introducing molding sand without organic additives leads to a marked reduction in CO at the work place.

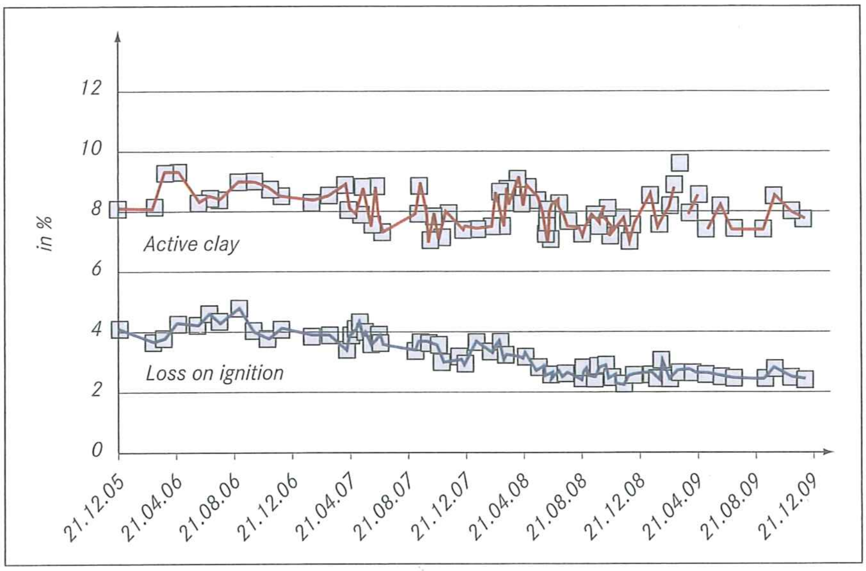

Figure 5: The loss on ignition indicates the changes in the molding sand; here a reduction from 4.0 % down to 2.3 %. The loss on ignition of 2.3 % is due to the process carbon (graphite) in the water of bentonite crystallization and the core binder residues.

while the expansion stress has decreased minimally.

Effects observed as a result of the use of inorganic additives as an alternative to lustrous carbon forming agents (coal):

» no fumes during pouring and cooling;
» reduction in CO load at the work place by approx. 30 %;
» high casting quality and high production security (scrap rate, metallurgy, productivity);
» low pyrolysis of sand (at approx. 500 °C);
» reduction in penetration defects, however, slight increase in strain-induced defects in casting (adjustment possible);
» the used sand is less heavily contaminated with organic hazardous substances;
» the molding material is no longer deep black.

nificantly (**Table 1**). There are indications that the strength values of the emission-reduced systems are lower at 350 °C (after cooling) and higher at 550 °C. The latter is presumably an effect of the coal. Further, it can be seen that at 750 °C the hot compression strength has remained the same,

All in all, the achieved effects are positive. A foundry, which has gone through the conversion, will not want to go back to coal-containing recipes.

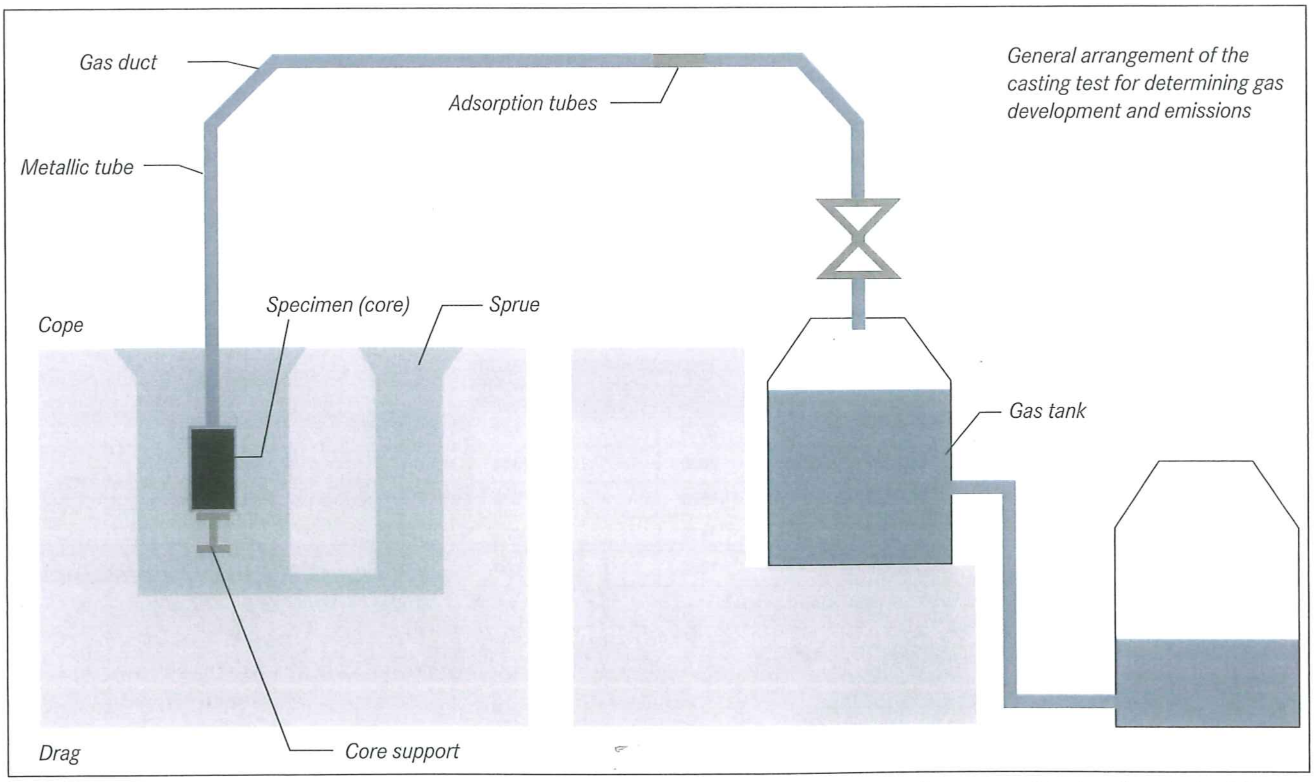

Figure 6: Schematic illustration of the BTEX emission measurement. The test piece (approx. 200 g) is flooded with molten metal. The arising BTEX components (benzene, etc.) are adsorbed on activated coal and then measured by HPLC. The benzene content decreased from 206 mg/kg in the molding sand down to 129 mg/kg as a result of the introduction of inorganic greensand additives.

Effect of the cores on emissions and greensand properties

The history of inorganic core binders used in the foundry industry is long. Under the current examination concerning the emissions – but also regarding the soiling of tools – these systems have been meeting with renewed interest. Binder systems on water-glass basis with additives and a curing process based on dehydration are generally employed today. By placing the cores in emission-free molds, CERP has found a way to distinguish between emissions from the mold sand and from the core sand. CERP measurements have shown that using inorganic core binders almost completely eliminates CO emissions.

Technological parameters	2007	2008	Change
Compactibility	41	40.9	-0.2
Moisture	3.38	3.45	2.1
Specimen weight	143	143	0.0
Green compression strength (N/cm^2)	17.7	16.6	-6.2
Hot compression strength (N/cm^2)			
150 °C/3 h	38.7	38.1	-1.6
350 °C/1.5 h	37.5	30.7	-18.1
550 °C/45 min	21	28.3	34.8
750 °C/30 min	14.9	14.9	0.0
Hot shear strength			
Heating up for 15 s	2.3	2.1	-8.7
Heating up for 60 s	3.7	4.7	27.0
Strain test (mm)			
Heating up for 30 s	0.15	0.17	13.3
Heating up for 60 s	0.33	0.33	0.0
Heating up for 180 s	0.6	0.58	-3.3
Strain during heating up (N/cm^2)			
30 s	9.22	9.09	-1.4
60 s	18.3	20.8	13.7
max	22.9	26.7	16.6

Table 1: Molding sand properties in 2007 (traditional molding material) and in 2008 after introducing inorganic additives (without coal in the blend). Generally, there are no significant changes that have a deteriorating effect on the molding material. Molding material pyrolysis at a lower temperature (350 °C) seems to be better; at 550 °C, the coal shows the expected effect towards moulding material pyrolysis. A striking result is that the dry strength values are highest at 150 °C.

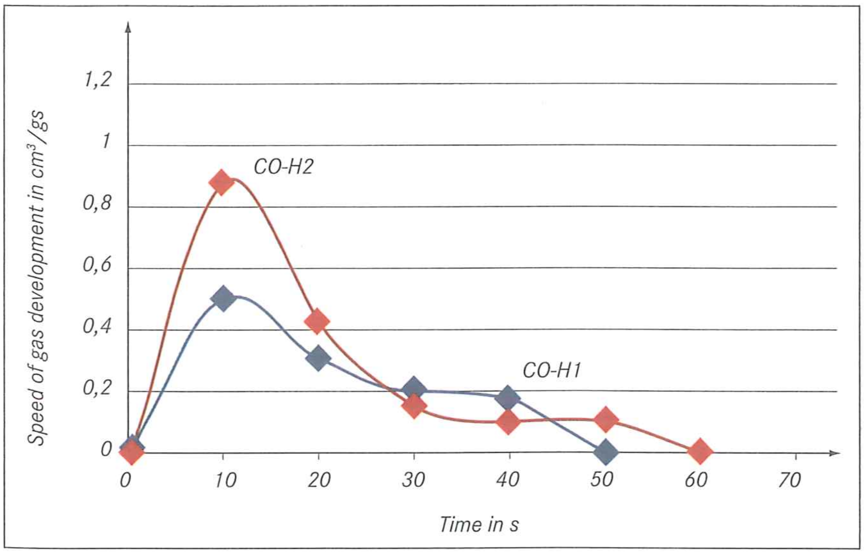

Figure 7: Inorganic molding sand additives markedly reduce the gas volume and gas shock. The reduction in emissions is likely to decrease gas-induced defects in the castings.

In the past, in core making, the water glass/CO_2 process was mostly used and, in mold making, the water glass/ester process. New systems based on curing by dehydration and the use of additives achieve better strength properties and higher productivities than the above mentioned methods. This, however, requires the use of hot toolings and hot air for drying. An alternative would be to dry the cores afterwards by microwaves.

Modifying water glass binders by additives has the following objectives:

- » high strength of the core when it is removed from the core box;
- » improved casting surface;
- » good pyrolysis of the core sand;
- » good flowability of the core sand;
- » less deformation during heating up;
- » longer storage times, also in more humid air;
- » better regeneration of the core sands (can also be influenced by the binder).

Core sand is frequently blended with the greensand system, resulting in a bentonite-bonded molding sand used in casting production. An examination was conducted to understand the effect of water-glass-based inorganic binders on molding sand or bentonite. Core sand was removed from aluminium castings and regenerated using bentonite and different quantities of new sand. These blends were investigated in order to determine their properties as molding material. Core binders of three different suppliers were used. The compositions of the binders and additives were not known in detail. Core sand additions of 25 % produced almost no problems; however, the wet tensile strength values fell from 0.30 N/m^2 to between 0.23 and 0.26 N/m^2. Using 100 % core sand led to markedly deteriorated molding sand properties; wet tensile strength fell from 0.30 N/cm^2 to between 0.10 and 0.18 N/cm^2. The dry compression

Test		Moisture	Added water	Compactibility	GCS	Permeability	GSS	WTS	DCS	Conductivity	pH
1	QS	2.61 %	70 ml	47	13.1	151	2.3 N/cm²	0.30 N/cm²	39.0 N/cm²	487 S/cm	10.73
2	50 % A	2.80 %	70 ml	47	9.2	128	1.1 N/cm²	0.18 N/cm²	23.6 N/cm²	628 S/cm	10.93
3	50 % B	2.64 %	70 ml	47	13.1	152	2.2 N/cm²	0.20 N/cm²	39.0 N/cm²	652 S/cm	11.00
4	50 % C	2.55 %	70 ml	46	12.6	150	2.0 N/cm²	0.24 N/cm²	28.9 N/cm²	552 S/cm	10.85
5	25 % A	2.61 %	70 ml	47	11.4	140	1.8 N/cm²	0.23 N/cm²	31.3 N/cm²	529 S/cm	10.90
6	25 % B	2.58 %	70 ml	47	13.1	146	2.3 N/cm²	0.26 N/cm²	35.0 N/cm²	620 S/cm	10.89
7	25 % C	2.59 %	68 ml	47	12.4	145	2.1 N/cm²	0.25 N/cm²	29.9 N/cm²	528 S/cm	10.77
8	100 % A	2.61 %	95 ml	47	5.9	110	0.5 N/cm²	0.10 N/cm²	18.1 N/cm²	711 S/cm	10.97
9	100 % B	2.89 %	75 ml	46	12.7	148	2.1 N/cm²	0.13 N/cm²	55.0 N/cm²	881 S/cm	11.25
10	100 % C	2.68 %	75 ml	47	10.6	146	1.9 N/cm²	0.18 N/cm²	32.0 N/cm²	707 S/cm	10.98

Table 2: Effect of inorganic binder (water-glass binder) on bentonite-bonded molding material. A compactibility value of 45 % ± 2 % was adjusted by addition of water. GCS – green compression strength, Perm. – permeability, GSS – green splitting strength, WTS – wet tensile strength, DCS – dry compression strength (150 °C/3 h dried), Conduct. - conductivity (µS/cm , 10 % in water).

strength values (150 °C/3 h) changed dramatically, from 39 N/cm² to between 18.1 and 55 N/cm². This is a clear indicator of the effect on core pyrolysis. Binder A additionally reduces gas permeability, probably as a result of the presence of certain additives (**Table 2**).

Obviously, the binder systems A, B and C have different – negative – effects on the molding material (bentonite). The exact influence can only be determined through a thorough study of the water glass binder and its additives as well as the bentonite – last but not least, to avoid bad surprises.

At the same time, it should be taken into account that inorganic binder systems do not produce any condensates that may modify the molding sand. Therefore, bentonite can be expected to have a positive effect on the binding properties. However, a critical aspect about this is the to be expected low level of organic/lustrous carbon forming agents in the molding sand, especially in molding sand systems with reduced or without additions of lustrous carbon forming agents (coal).

Summary

Lustrous carbon forming agents like coal in bentonite-bonded molds can be partly or completely replaced by inorganic additives. This has a number of advantages:

» no fumes during pouring and cooling;
» clearly reduced amount of CO at the work place (approx. 30%);
» reduction in benzene (BTEX) emissions (approx. 40%);
» less odours at knocking-out station (indicative measurement);
» unchanged casting surface;
» greensand properties do not change significantly;
» total scrap and reworking rates are the same;
» markedly fewer penetration defects, more defects due to mold expansion.

The transition from lustrous carbon forming agents (coal) to inorganic additives should be implemented at a low pace so that the process can take place in a controlled manner, effects can be quantified and, if necessary, the process or the additives can be adjusted to the new situation.

Introducing inorganic core binders has the following advantages:

» no or – compared to organic binders, such as polyurethane cold box – only very few emissions and condensates;
» curing by drying; hot air or microwaves to not negatively affect the conditions at the work place;
» the used binder components are less hazardous to the environment and humans;
» the binder does not form any crack residues during heating, which are hazardous and contaminate the molding sand or the used sand to be regenerated;
» with thin/small cores short cycle times can be achieved.

Inorganic core binders require hot toolings and curing by dehydration. This is more efficient for large-series production.

Conclusions

It is possible to replace 50 to 100 % of the organic additions (lustrous carbon forming agents) in greensand systems, i.e. bentonite-bonded molding materials, by inorganic additives.

Also cores can be made with inorganic binders, usually based on water glass with various additives. Use of these binders is most promising in aluminium casting and for small cores in large-series casting.

Future challenges will be the development of inorganic cores for iron and steel casting and the study of there interaction with bentonite-bonded molding material. This necessitates detailed knowledge of the entire process as well as the properties and interacting effects of core binders and bentonite, including the employed additives.

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References

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