FOSECO

INNOVATIVE WASCO* WATER-SOLUBLE BINDER SYSTEMS FOR HPDC APPLICATIONS

Authors: Vincent Haanappel,
Thomas Linke

For HPDC applications, Foseco developed a new type of sand core using innovative WASCO water-soluble binder systems and optionally with adaptable coatings to avoid liquid metal penetration into the pores of the sand core.

This paper focuses first on some fundamental aspects on the development of such a water-soluble binder system, followed by 2 practical examples, one producing cores for explosion-proof instrument housings, and the other manufacturing sand cores for automotive applications. Irrespective of the high flexural strength of the sand cores, after the casting process the complete casting was immersed in cold water after which the binder showed excellent water-solubility. Due to the short cycle times resulting in a relatively low thermal impact, no issues occurred with the generation of volatile organic compounds (VOC's) as the organic binder thermally decomposes.

After washing-out core residue, a smooth, defect-free and sand-free casting surface was obtained, indicating that the sand cores with the WASCO water-soluble binder can be a promising candidate for structural castings.

*WASCO is a trademark of the Vesuvius Group, registered in certain countries, used under licence.

> BACK TO OVERVIEW

INTRODUCTION

In most casting processes, the molten metal is poured in a pre-formed mould, with the metal filling of the mould under gravity or low pressures resulting in the need for slightly higher metal temperatures to ensure a complete casting fill. When applicable the internal cavities needed in the castings are commonly defined by the use of disposable cores, which is typically an inorganic or organic resin-bonded sand core. Advantage of such a system is that due to the heat from the molten metal, the resin binder in the core starts to degrade resulting in an easy shaking out of the core residue. In die casting processes, such as Semi-Solid Casting [1-4] or High Pressure Die Casting (HPDC) [5-10], the metal is cooled very quickly, so the core itself will not be exposed anymore to high temperatures. Combined with the high core strengths needed to withstand these filling pressures, this results in difficulties to remove the sand core after the casting has solidified. Furthermore, the core will only be exposed for a short time to elevated temperatures up to 300 – 400 °C, which is insufficient to thermally decompose the binder.

This paper is focusing on the development of cores suitable for HPDC, consisting of a liquid polymer binder and a powder-like solid consisting of (various) minerals. This new and innovative WASCO water-soluble binder system is developed by Foseco.

Achieving high quality castings with the use of cores including the WASCO water-soluble binder system depends not only on the casting process itself and their processing parameters, but also on the quality of these cores. Use of cores with insufficient strength or with locally low compaction results in lower surface smoothness and can result in defects of the casting surface if not properly controlled. The main requirements to achieve high quality castings (from HPDC, Semi-solid processes) and received from the foundry industry are:

- High strength values
- Sufficient water solubility after the casting process
- No gas formation during the casting process
- Use of cost-effective and non-dangerous materials
- Easy to handle and able to be to mixed with various types of sand
- Sufficient bench life of the sand mixture
- Good flowability of the sand mixture
- High quality cores with sufficient compaction and surface smoothness
- Short cycle times = short core production times

Some fundamentals are highlighted on the manufacturing of cores based on sand and optionally with the presence of a coating. In more detail, flowability of the sand mixture, mechanical strength, surface smoothness, water solubility of the binder, and first casting results from HPDC processes will be presented.

EXPERIMENTAL AND RESULTS

First step in the optimization of sand cores for HPDC applications was based on a 2-component liquid binder system and one additive. In this part, the ratio between both components were tested on flowability of the sand mixture, flexural strength and water solubility of non-treated sand cores and those treated for 2 hours at 140 °C and 200 °C (Table 1). These testing conditions were chosen to find out the optimum ratio for best performance on strength and water solubility.

Using the Powder Flow Tester Brookfield [11], the flowability of the various batches was determined and listed in Table 2. It was clear that the higher the contribution of component D, the higher the flowability; corresponding with the lowest consolidation stress.

Flexural strength was measured using standard-type transverse bars with dimensions of 22.4 x 22.4 x 180 mm. The flexure test (three-point measurement) measures the bending behavior of material subjected to simple beam loading. The flexural strength as a function of a 2-component liquid binder consisting of a liquid LB_A and a liquid LB_D is determined. The total addition rate of the liquid is kept constant at 5.0 wt%. Regarding the additive, a concentration of 2.0 wt% was chosen. All samples were manufactured with quartz sand H33 (Quarzwerke, Germany).

Composition:	1	2	3	4	5	6
2-C Liquid Binder	5.0 wt%	5.0 wt%	5.0 wt%	5.0 wt%	5.0 wt%	5.0 wt%
Comp. D (wt%)	0	20	40	60	80	100
Comp. A (wt%)	100	80	60	40	20	0
Additive	2.0 wt%	2.0 wt%	2.0 wt%	2.0 wt%	2.0 wt%	2.0 wt%
Heat treatment – 0	None	None	None	None	None	None
Heat treatment – 1	2h/140°C	2h/140°C	2h/140°C	2h/140°C	2h/140°C	2h/140°C
Heat treatment – 2	2h/200°C	2h/200°C	2h/200°C	2h/200°C	2h/200°C	2h/200°C

Table 1: Composition of various batches with a 2-component liquid binder.

Composition:	1	2	3	4	5	6
2-C Liquid Binder	5.0 wt%	5.0 wt%	5.0 wt%	5.0 wt%	5.0 wt%	5.0 wt%
Comp. D (wt%)	0	20	40	60	80	100
Comp. A (wt%)	100	80	60	40	20	0
Additive	2.0 wt%	2.0 wt%	2.0 wt%	2.0 wt%	2.0 wt%	2.0 wt%
Flowability - Consolidation stress (kPa) as function of the compressive strength						
0.60 kPa	0.45	0.39	0.38	0.42	0.42	0.40
1.13 kPa	0.63	0.58	0.56	0.56	0.57	0.56
2.19 kPa	0.84	0.80	0.73	0.71	0.72	0.72
4.35 kPa	1.11	1.02	0.92	0.86	0.87	0.89
8.70 kPa	1.37	1.33	1.14	1.03	1.06	1.08

Table 2: Flowability (consolidation stress as a function of the compressive strength) of various sand mixtures with a 2-component liquid binder and as a function of the LB_A / LB_D ratio.

<

>

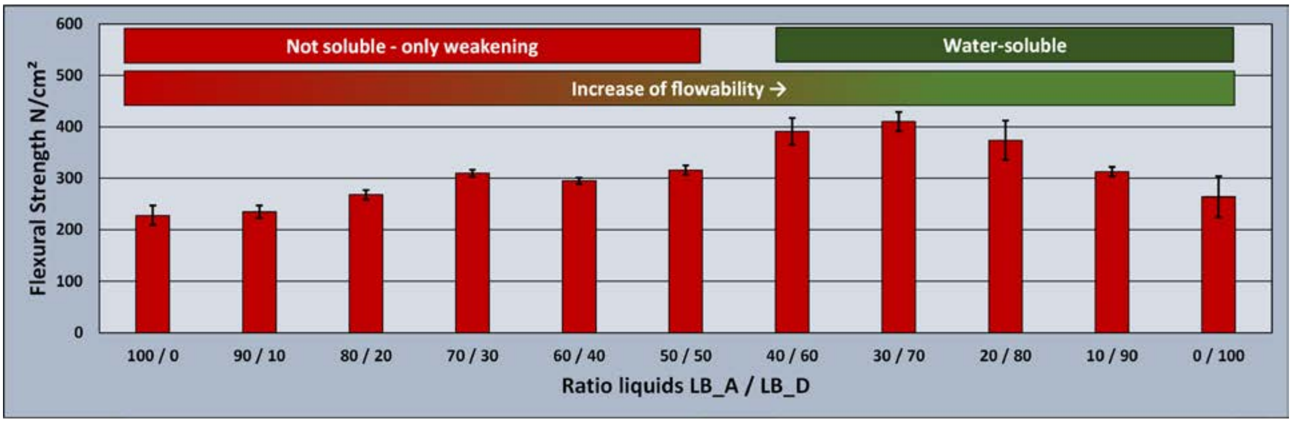


Figure 1: Flexural strength of sand cores (quartz sand H33) as a function of the type of liquid binder with various ratio's LB_A / LB_D.

From Figure 1 it is obvious that the flexural strength showed a maximum for the ratio 30 / 70, thus with 30 wt% LB_A and 70 wt% LB_D. Considering the potential applications of such types of sand cores, these cores should also meet other requirements, in particular water-solubility.

Solubility of the binder was determined by immersing cylinder-type cores in cold (20 °C) or hot (65 °C) tap water and with a rotation speed of 60 rpm (in cold water) and 150 rpm (in hot water); the first one related to moderate conditions and the other to more severe conditions. The outcome of the immersion test is shown in Table 3.

Composition:	1	2	3	4	5	6
2-C Liquid Binder	5.0 wt%	5.0 wt%	5.0 wt%	5.0 wt%	5.0 wt%	5.0 wt%
Comp. D (wt%)	0	20	40	60	80	100
Comp. A (wt%)	100	80	60	40	20	0
Additive	2.0 wt%	2.0 wt%	2.0 wt%	2.0 wt%	2.0 wt%	2.0 wt%
Water-solubility						
As-received	5 – 10 s	5 – 10 s	5 – 10 s	10 – 15 s	20 – 25 s	20 – 30 s
2 h / 140 °C	20 – 30 s	10 – 15 s	15 – 25 s	5 – 10 s	20 – 30 s	20 – 25 s
2 h / 200 °C	weakening	weakening	weakening	50 – 60 s	30 – 40 s	30 – 40 s

Table 3: Water solubility of various sand cores with a 2-component liquid binder and as a function of the LB_A / LB_D ratio and without or with a heat treatment.

Interesting to observe is that the as-received samples with the highest contribution of component A showed fast solubility, whereas those with a higher concentration of component D showed a slightly slower solubility rate. After the cores were exposed to heat for 2 h at 200 °C, those with a relatively high contribution of component A were not soluble, only weakening of the sand cores occurred. Since the application of these sand cores will be exposed to elevated temperatures during casting and cooling, those with the highest addition rate of component D is recommended.
In case of using these formulations for sand cores for HPDC high flexural strength is needed, this to avoid core breakage during the casting process. Figure 2 shows the flexural strength as a function of the grain size of the additive and the concentration. In case of an addition rate of 2.0 wt%, highest flexural strength was achieved with a grain size of 12 µm. This strength decreased to lower values with an increase of the grain size from 41 µm, 100 µm to 146 µm. From this figure it is clear that the smaller the average grain size of additive as well as the higher the addition rate, the higher the flexural strength of the sand cores. During HPDC process the liquid metal is fed under high pressure into the die and solidified to obtain the desired component. This process takes place in a fraction of seconds. The general description is that cores with 1000 N/cm² or higher are targeted [6-10].

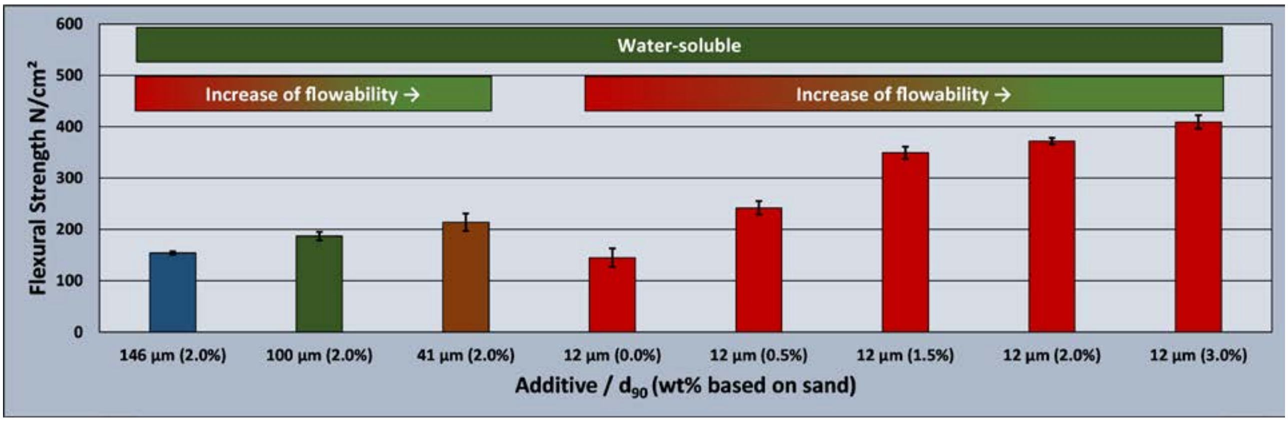


Figure 2: Flexural strength of sand cores (quartz sand H33) as a function of the grain size of the additive. The LB_A / LB_D ratio was set at 30 / 70 (5.0 wt%) and the additive concentration at 2.0 wt%.

<

>

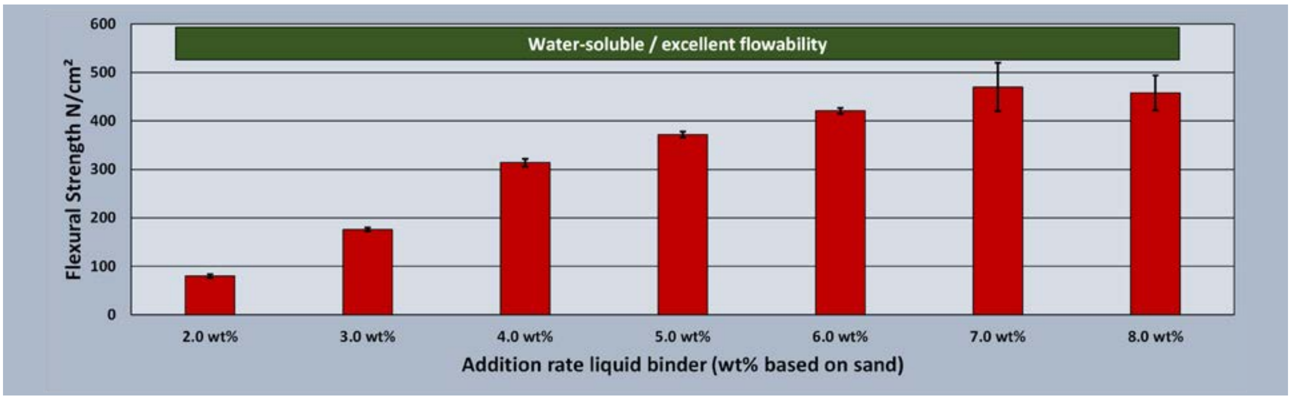


Figure 3: Flexural strength of sand cores (quartz sand H33) as a function of the addition rate of the liquid binder. the LB_A / LB_D ratio was set at 30 / 70 and the additive concentration at 2.0 wt%.

To improve further the mechanical properties, the flexural strength as a function of the addition rate of the liquid binder was investigated. Figure 3 shows the data of the flexural strength and in relation to the amount of liquid binder added to the sand mixture. In this case the concentration of the additive was set at 2.0 wt%. Interesting to observe is that the strength values increased with a higher addition rate of the liquid binder up to 7.0 wt%. More binder did not result anymore in higher strength values, this due to a certain over-saturation. This means that the highest flexural strength values were achieved with a combination of the individual liquids LB_A and LB_D and with an addition rate of 7.0 wt%.

Higher flexural strength values will now only be achieved when more attention is paid on the type and concentration of the additive(s). Since the usage of the additive resulted in flexural strength values up to about 500 N/cm², different types of other minerals or components were considered too.

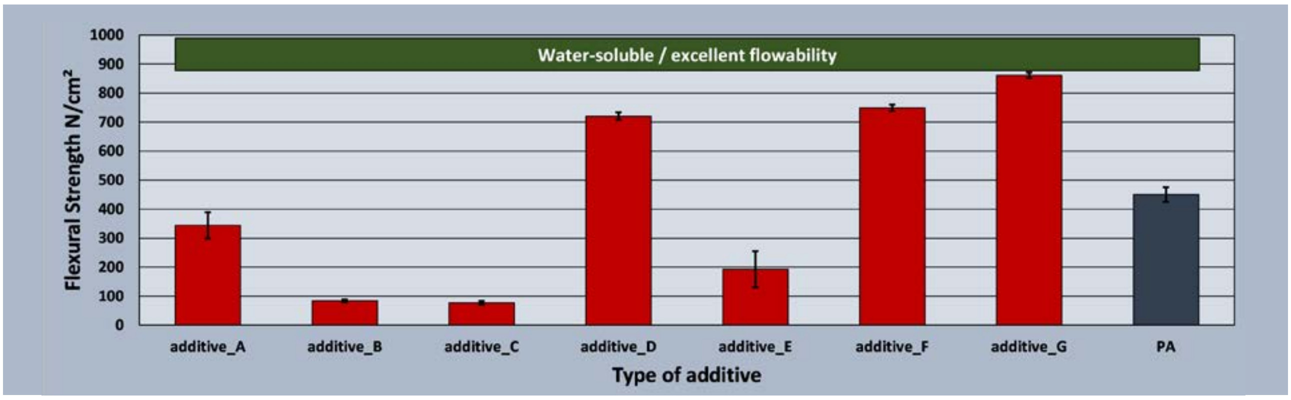


Figure 4: Flexural strength of sand cores (quartz sand H33) as a function of the type of additive. The liquid binder LB_A / LB_D ratio was set at 30 / 70 and at 4.0 wt% and the additive concentration was 4.0 wt%.

It is well-known [12,13] that in case of inorganic binder systems, other types of additives can achieve high strength values. Based on these documents, a selection was made of certain types of additives indicated as A – G. Figure 4 shows the flexural strength as a function of these various types of additives. Based on these values, also another type of additive was chosen indicated as type S. With this additive strength values could be achieved up to values higher than 1200 N/cm², as shown in Figure 5.

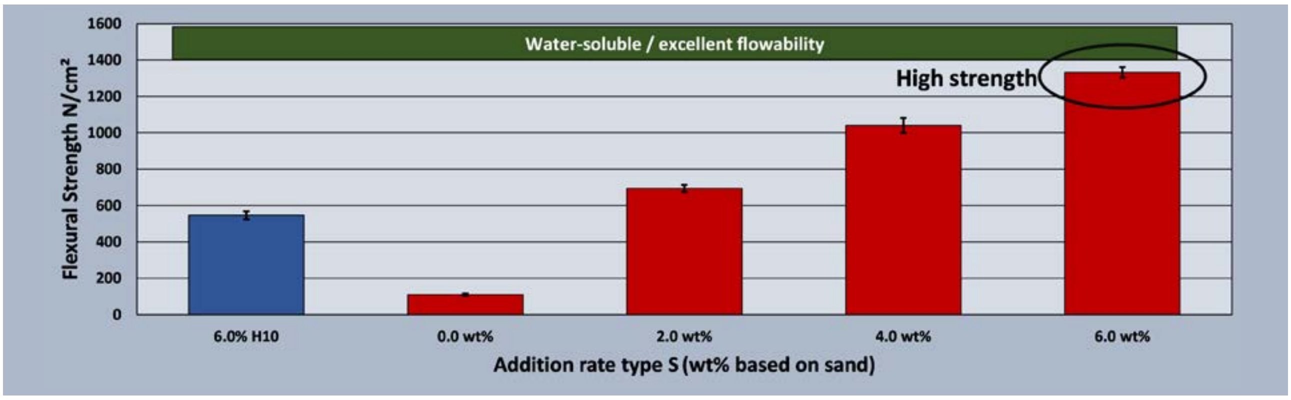
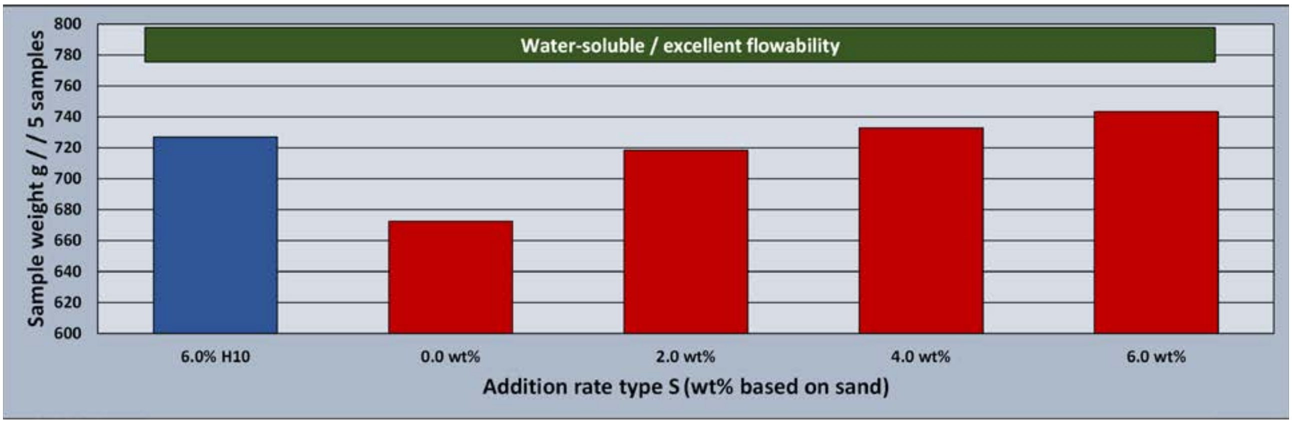


Figure 5: Flexural strength of sand cores (quartz sand H33) as a function of the addition rate of the additive S. The liquid binder (6.0 wt%) LB_A / LB_D ratio was set at 30 / 70.

Since this type of additive, here type S showed very promising results, also flowability of the modified sand mixture has to be determined again. More information about measuring and improving flowability of sand mixtures can be found in reference [14].
The fastest indirect method to obtain information about flowability of the sand mixtures is related to the core or sample weight after curing. In relation to Figure 5, showing the bending strength values as a function of the addition rate of type S, Figure 6 shows the corresponding sample weight as a function of the amount of type S added to the sand mixture. In case no additive was added, the sample weight was about 670 g (5 samples), but with an increase of the amount of the additive, the sample weight also increased up to values of around 740 g (with 6.0 wt%). Worth to mention is that the additive particles are completely spherical which induced higher flowability of the sand mixture. On the contrary, irregular shaped particles resulted generally in lower flowability. The type of sand can also be a parameter to affect flowability. The most important structural parameters influencing the flowability of the sand mixture are the average grain size and grain size distribution and the shape (angular or well-rounded and with low sphericity or high sphericity). Foundries generally will use the sand that is available from a local quarry near the production site, this to reduce transport costs. This means that flexibility in the type of sand is very limited which means that the type is generally a given parameter hardly to be replaced by another type of sand.



<

Figure 6: Sample weight of sand cores (quartz sand H33) as a function of the addition rate of the additive S. The liquid binder (6.0 wt%) LB_A / LB_D ratio was set at 30 / 70.

>

One main component of a sand mixture with a water-soluble binder system is the liquid part of the binder. As already reported, this liquid binder is a 2-component polymer system based on one liquid type LB_A and one on type LB_D and with addition of a small amount of water and with a special type of surface-active agent. In case the viscosity of the liquid binder is high, it will have a detrimental impact on flowability and therefore on the quality of the sand cores. With a water-based polymer solution, a lower viscosity can be achieved in case the chain length of the polymer is shorter, thus with a lower n-value. The viscosity of a polymer can be expressed by the Mark-Houwink equation:

$$\eta = K.M\alpha$$

whereas η = viscosity of the polymer, K and α depend on the specific polymer, and M = molecular weight.

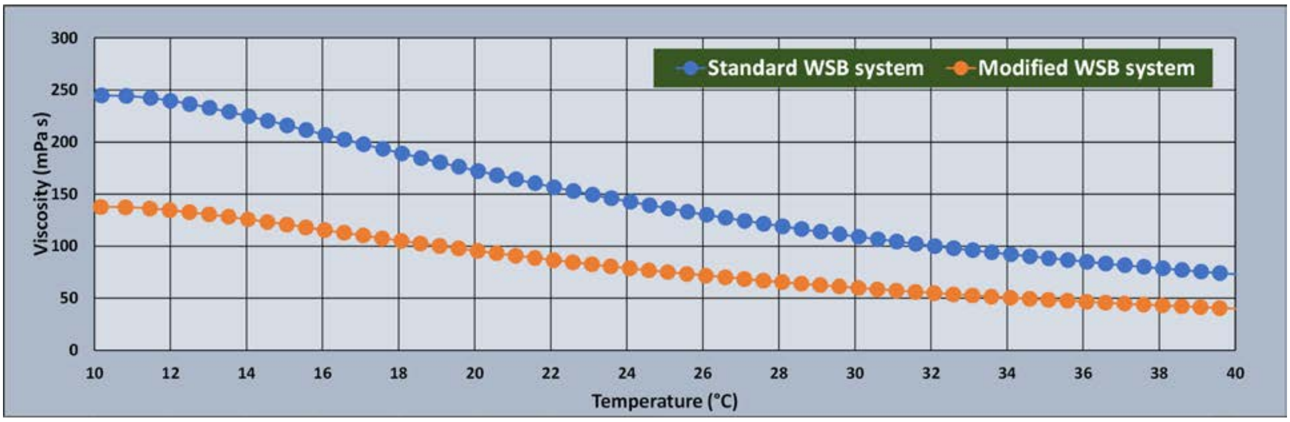


Figure 7: Viscosity of the standard WASCO system (blue) and the modified WASCO system (orange) as a function of the temperature.

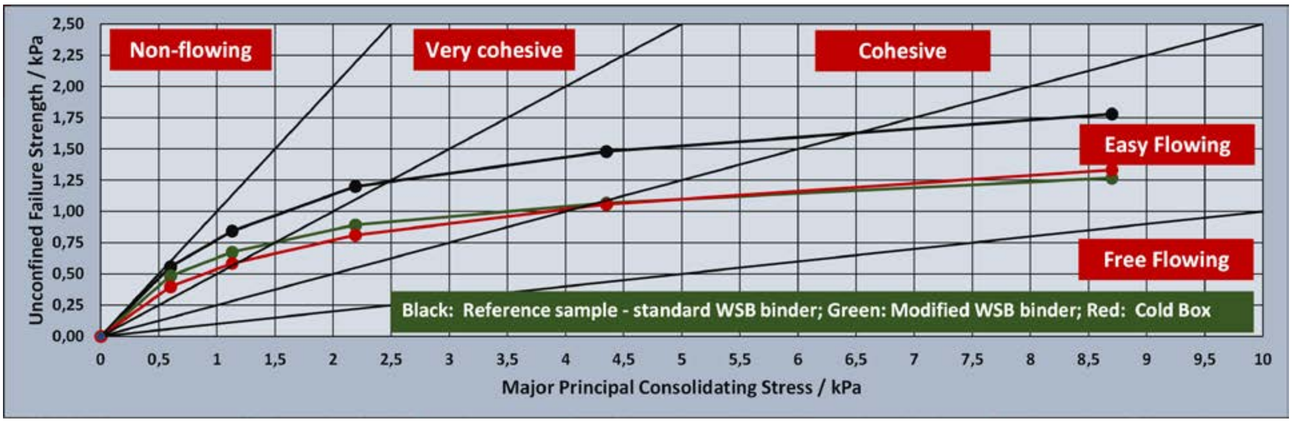


Figure 8: Unconfined failure strength versus major principal consolidating stress for three various sand mixtures: black: standard-type of the WASCO water-soluble binder system; green: modified WASCO water-soluble binder system with shorter chain length; red: PU cold box system.

2 types of the WASCO water-soluble binders were considered, one the standard-type and the other with a shorter chain length of the polymer. The viscosity of both WASCO water-soluble binder systems was measured between 10 °C and 40 °C and results are depicted in Figure 7. From this plot, it can be concluded that between the above given temperature range, the viscosity of the modified WASCO water-soluble binder system is always significantly lower than that of the standard WASCO water-soluble binder system. Figure 8 shows the flowability curves, one corresponds with the reference sample prepared with the standard-type of organic-based water-soluble binder system (black curve), the second one with the modified organic binder including a shorter chain length (green curve), and the third with the standard cold box system. Clear is that the flowability of the sand mixture with the modified organic-based water-soluble binder is significantly higher.

The influence of the modified WASCO water-soluble binder system was further investigated with a series of core manufacturing, in this case transverse bars. The shooting parameters with the L1 Laempe core shooter were 4 bar shooting pressure and 0.4 s shooting time. The prepared sand mixture was first stored under various temperatures, here between 10 °C and 25 °C and with steps of 5 °C. Results from these tests are visualized in Figure 9. With the standard WASCO water-soluble binder system and under relatively cold conditions, no complete sand cores could be produced. Due to the high viscosity of the liquid binder, in particular at 10 °C and 15 °C, flowability is too low to completely fill the cavities of the core box. Only at higher temperatures, here 20 °C or 25 °C, complete cores could be produced. In case of the modified WASCO water-soluble binder system, characterized by a significantly lower viscosity, even at 10 °C, complete sand cores could be produced, even at the lowest test temperature. Generally, a lower viscosity will result in defect-free sand cores with high compaction.

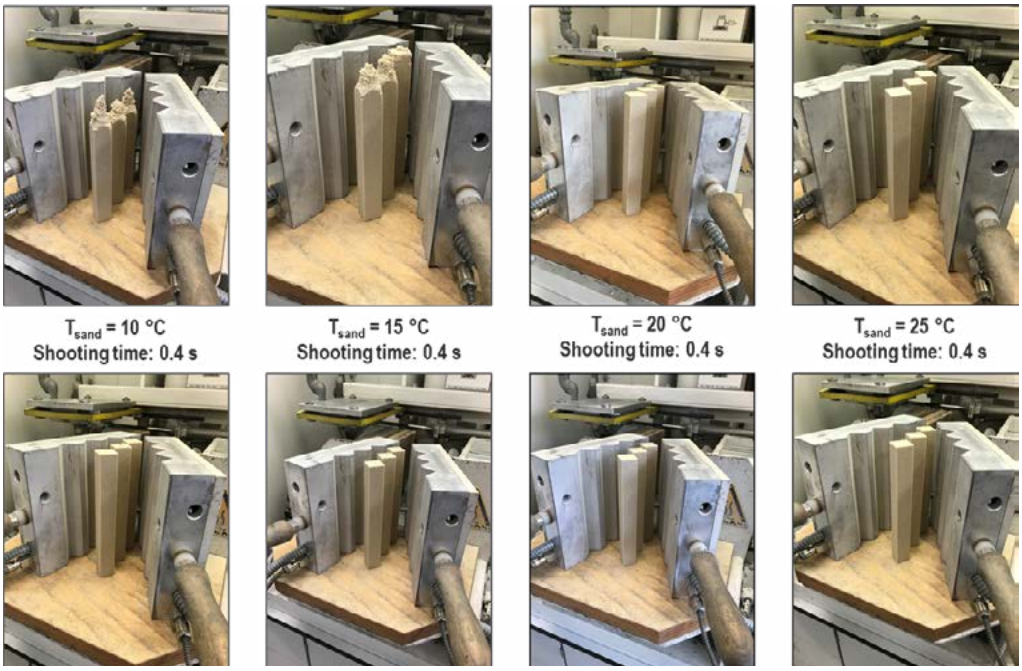


Figure 9:
Core manufacturing (transverse bars) with the standard-type WASCO water-soluble binder system (upper pictures) and with the modified WASCO water-soluble binder system (bottom pictures). In all cases, the shooting time was set at 0.4 s. The addition rate of the liquid binder was set at 6.0 wt% and of the additive at 4.0 wt%.

TESTING TRIALS-ON-SITE I

This chapter is dealing with a project aiming to manufacture explosion-proof instrument housings. Figure 10 shows a schematic view of this housings with the designed sand core. First step in this was to start with a non-coated or unsealed sand core, this to investigate in more detail the surface quality of the castings.

After the casting process all castings were immersed in cold water. Within a very short time, all sand cores could easily be removed due to the high solubility of the binder.

Figure 11 shows the inner surface of the casting in case a non-coated sand core was used. The surface shows high roughness with severe sand adhesion, this due to metal penetration into the pores of the sand core. Even with a Kärcher pressure washer, the adhered sand grains could not be removed.

To avoid metal penetration finally resulting in severe sand adhesion, a special type of waterborne coating was developed. Such a coating could be applied by the dipping process, followed by furnace drying at 120 °C. Figure 12 shows 3 sand cores with the waterborne coating, after dipping and after furnace drying at 120 °C for 1 h.

With the application of a coating to avoid metal penetration a smooth and sand-free casting surface was achieved. Figure 13 shows the final product fulfilling the following main requirements: good flowability of the sand mixture resulting in defect-free sand cores, high mechanical strength, easy to apply a waterborne coating, fast solubility of the binder after the casting process, smooth and sand-free casting surface.

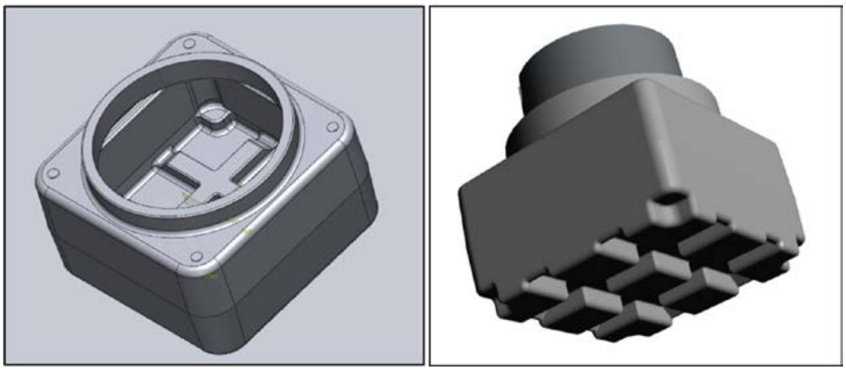


Figure 10: left: schematic view of an explosion-proof instrument housings; right: drawing of the developed core (courtesy Limatherm S.A. Poland)

Figure 11: Left: non-coated sand core; middle and right: inner casting surface with significant sand adhesion.

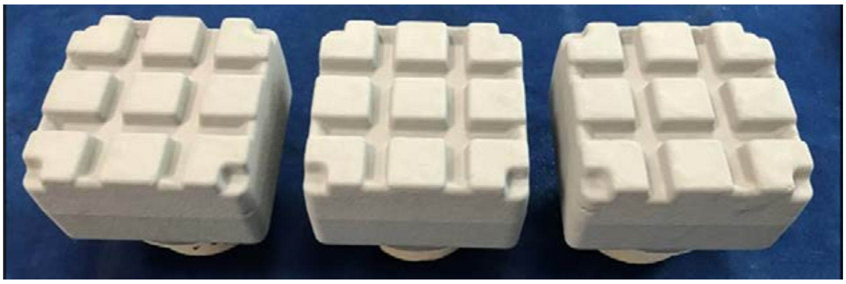


Figure 12: Sand cores with a coating applied by dipping. The coating was furnace dried at 120 °C for 1 h.

Figure 13: Inner surface of the casting (explosion-proof instrument housing) after removing the coated sand core (courtesy Limatherm S.A. Poland).

<

>

TESTING TRIALS-ON-SITE II

The second series of sand cores manufactured with the WASCO water-soluble binder system is dealing with an example of potential automotive applications for HPDC. In particular the production of light-weight hollow parts is key in this project.

As already mentioned, the presence of a coating is needed, this to avoid metal penetration and sand adhesion. Sand cores could be dipped or the coating could be applied by spraying. In both cases, a dense and compact coating layer was applied (see Figure 14). After solidification, the castings were ejected from the mould and directly immersed in a water bath. All castings were collected followed by a further cleaning of the inner surface.

After cross sectioning the castings, it was obvious that the use of sand cores without a coating resulted in severe sand adhesion, as can be observed from Figure 15.

With the presence of a coating, no sand adhesion occurred and the inner casting surface showed an acceptable surface quality (see Figure 16).

In some specific complex regions of the core surface, a secondary process using a Kärcher pressure jet wash enabled a completely sand-free casting surface.

Figure 16 shows the casting on the left and on the right part of the inner surface.

Surface roughness of both casting pieces, non-coated and coated, was also determined by a 3D image of the surface, measured with the Keyence surface profilometer (Figure 17). Clear is the high smoothness of the surface in case a coated sand core was used.

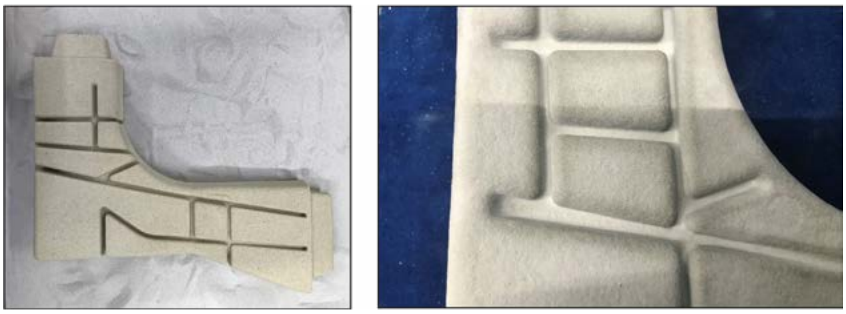


Figure 14: Left: uncoated sand core; Right: higher magnification of the surface with an applied water-borne coating


Figure 15: Inner casting surface after cross sectioning of the castings. Left: after removing a non-coated sand core; right: after removing a coated sand core


Figure 16: Sand cores with a coating applied by dipping. The coating was furnace dried at 120 °C for 1 h.

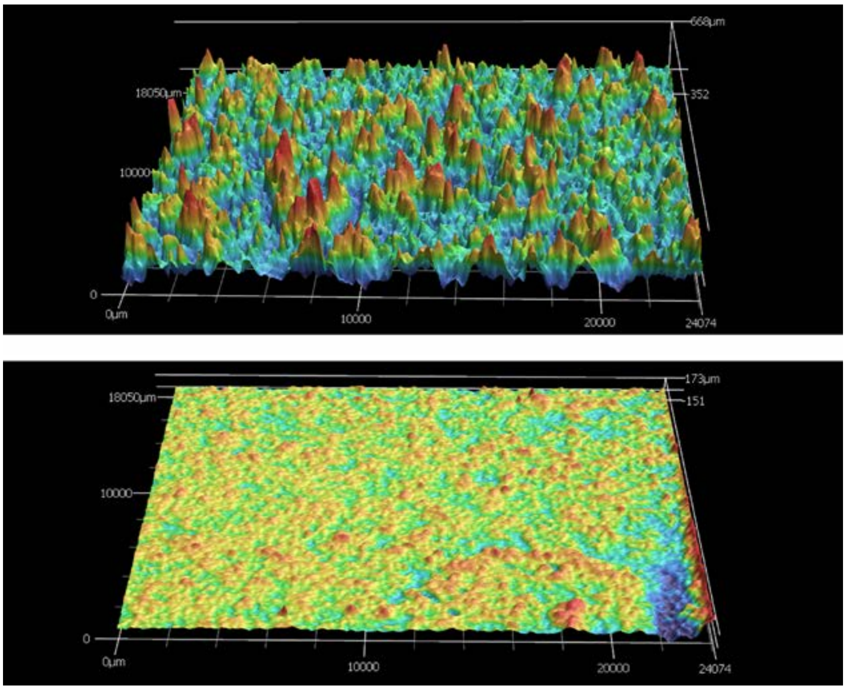


Figure 17: Inner surface of the casting (explosion-proof instrument housing) after removing the coated sand core.

<

>

CONCLUSIONS

The new and innovative WASCO water-soluble binder system developed by the Foseco has demonstrated their high strength in severe processing conditions, such as HPDC. With the use of an appropriate and compatible coating, these innovative sand cores can withstand high pressures and temperatures whilst facilitating easy core removal from internal cavities by flushing water, leaving a smooth and sand-free surface.

This WASCO system demonstrated the strong potential and can meet a wide range of customer requirements, showing very promising results not only for liquid HPDC, but also for Semi-solid processes.

Main advantages of the new WASCO system are:

a) Strength values exceeding 1000 N/cm² are achievable.
b) Core residue is easy to remove and without use of mechanical force.
c) Use of cost-effective materials.
d) High flexibility in the use of additives.
b) Core manufacturing uses only standard hot box core shooters with hot air purge

ABOUT THE AUTHORS

Vincent joined Foseco in 2011. He is currently R&D Manager for Binders at our Global R&D Centre, where he leads development of our innovative and environmentally-friendly inorganic binders. Outside work, Vincent enjoys spending time with his family, cycling, playing the organ and piano, cooking, and learning languages.

GET IN TOUCH WITH VINCENT

LinkedIn-Profile

vincent.haanappel@vesuvius.com

VINCENT HAANAPPEL
R&D Manager Binders

Thomas joined Foseco in 2011. He is currently Global Product Manager Non-Ferrous Binders and Coatings. He leads projects to bring the developed innovative products to the market. Outside work, Thomas enjoys gardening, hiking, music and spending time with his family.

GET IN TOUCH WITH THOMAS

LinkedIn-Profile

thomas.linke@vesuvius.com

THOMAS LINKE
Global Product Manager
Mould & Core

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the management team Foundry and the complete R&D Mould and Core team of the Foseco R&D centre in Enschede, the Netherlands.

The Foseco R&D centre, Enschede, the Netherlands, is also grateful to Limatherm S.A., Poland for their support and contributions.

REFERENCES

[1] Haga, T., Kapranos, P., Simple rheocasting processes, Journal of Materials Processing Technology 130-131, 2002, pp. 594-598.

[2] Bührig-Polaczek, A., Heiner, M., Bünck, M., Suitability of lost cores in rheocasting process, In Proceedings of the 11th International Conference on Semi-Solid Processing of Alloy and Composites : September 16 - 18, 2010, Beijing, China / S. J. Luo; W. C. Keung; Y. L. Kang.

[3] Winklhofer, J., Semi-Solid Casting of Aluminium from an Industrial Point of View, Solid State Phenomena 285, 2019, pp. 24-30.

[4] Payandeh, M., Rheocasting of aluminium alloys: Process and Components Characteristics, Dissertation 2016, Jönköping University, Jönköping, Sweden.

[5] Ming Fan Qi, Yong Lin Kang, Quan Quan Qiu, Industrialized Application of Rheo-HPDC Process for the Production of Large Thin-Walled Aluminum Alloy Parts, Solid State Phenomena 285, 2019, pp. 453-458.

[6] Jelinek, P., Adámková, E., Lost cores for high pressure die casting, Archives of Foundry Engineering, 14(2), 2014, pp. 101-104.

[7] Casarotto, F., Franke, A.J., Franke, R. - High-pressure die-cast (HPDC) aluminium alloys for automotive applications, Advanced Materials in Automotive Engineering, 2012, pp. 109-149.

[8] Jelínek, P., Adámková, E., Lost Cores for High-Pressure Die Casting, Archives of Foundry Engineering DOI: 10.2478/afe-2014-0045, 14, 2014/2, pp. 101 – 104.

[9] Fuchs, B., Eibisch, H., Körner, C., Core Viability Simulation for Salt Core Technology in High-Pressure Die Casting, International Journal of Metalcasting, 7, 2013, pp. 39 – 45.

[10] Cantas, C., Baksan, B., Effects of Composition on the Physical Properties of Water-Soluble Salt Cores, International Journal of Metalcasting, 15, 2021, pp. 839 – 851.

[11] Schulze, D., Powders and Bulk Solids - Behavior, Characterization, Storage and Flow. Berlin, Heidelberg, Germany: Springer-Verlag; 2008. DOI: 10.1007/978-3-540-73768-1. Available from: https://www.dietmar-schulze.de/pdf/ flowproperties.pdf.

[12] Song, L., Liu, W., Xin, F., Li, Y., Effect of Silica Fume on Humidity Resistance of Sodium Silicate Binder for Core-making Process, International Journal of Metal Casting, 14, 2020, pp. 977 – 986. 2020, DOI:10.1007/s40962-019-00405-1.

[13] EP 2 359 957 A1, Method and composition for the preparation of foundry moulds and cores - European Patent Office, FOSECO INTERNATIONAL LIMITED, Central Park, Barlborough Links, Derbyshire S43 4XA (GB)).

[14] Haanappel, V., Methods to determine, influence and improve the flowability of sand mixtures, in Casting Processes, ed. T.R. Vijayaram, IntechOpen, United Kingdom, 2022, pp. 47-66. ISBN 978-1-80355-495-2.

<

>