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ECIG 2025
Milan - 29-30 April 2025

AGH University of Krakow · Faculty of Foundry Engineering · Aalto University School of Engineering · Consiglio Nazionale delle Ricerche · ICMATE

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Networking for advancing excellence and capacity in light-weight castings for Foundry 4.0 in Poland

Effect of binder type on properties of molding sands dedicated to 3D printing

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3D printing - binder jetting technology

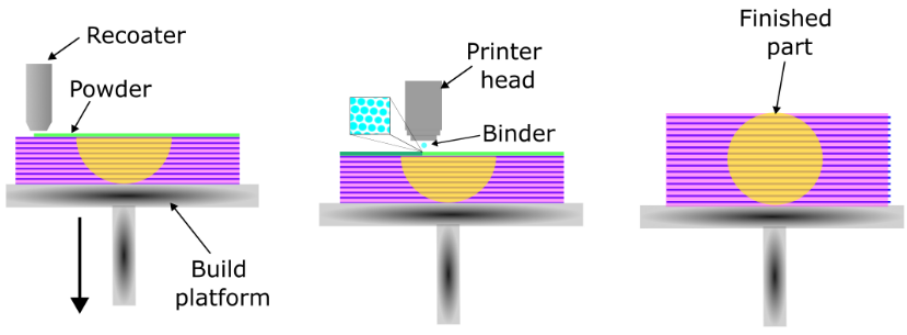

Fig. 1. Scheme of the sand 3D printing process using the binder jetting method.

Produced in binder jetting (3D printing) technology sand molds and cores are succesfully used in the production of castings and their number constantly increases. The technology enables the production of molds and cores with complex shapes that are impossible to achieve using conventional methods, which can be useful in the production of thin-walled cast iron castings.
The technology is aligned with **Industry 4.0** concept.

Layer thickness: 0.28 - 0.50 mm

sand matrix:
silica sand, chromite sand
with grain size 0.14-0.25 mm

binder:

furfuryl resin	1.0 – 2.4%
phenolic resin	2.2 – 2.4%

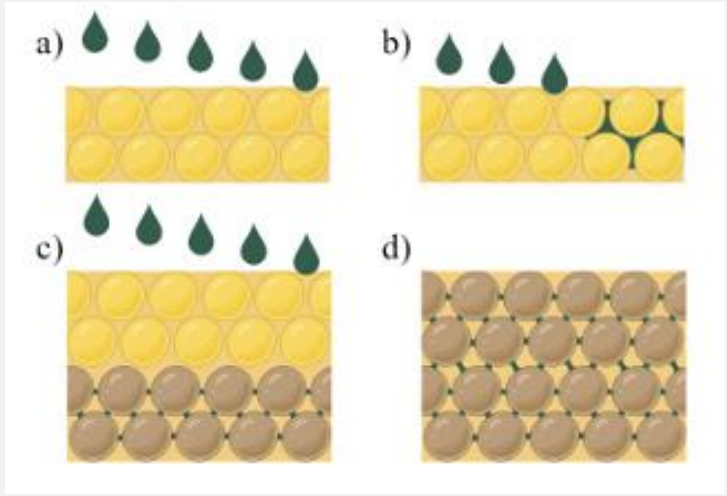

Fig. 2. Printing process in binder jetting 3D system: a) droplets of liquid binder are applied to layer of matrix; b) binder surrounds sand grains; c) droplets of binder applied to new layer of matrix; d) matrix grains connected by resin bridges.

Jandyal, A., Chaturvedi, I., Wazir, I., Raina, A. & Ul Haq,M.I. (2022) 3D printing – A review of processes, materials and applications in industry 4.0. Sustainable Operations and Computers. 3, 33-42. DOI: 0.1016/j.susoc.2021.09.004
Upadyay M., Sivarupan T. & El Monsori M. (2017) 3D rapid for sand casting – A review Journal of Manufacturing Processes. 29, 211-220 DOI: : 10.1007/s00170-018-2020-z.

3D printing - binder jetting technology

Advantages

- good dimensional accuracy,
- low roughness of mold cavity,
- lower binder content,
- shorter hardening time,
- production of shapes not possible to achieve with the use of conventional molding methods.

Disadvantages

- high machine costs,
- limitations in large-scale production,
- possible stepping effect.

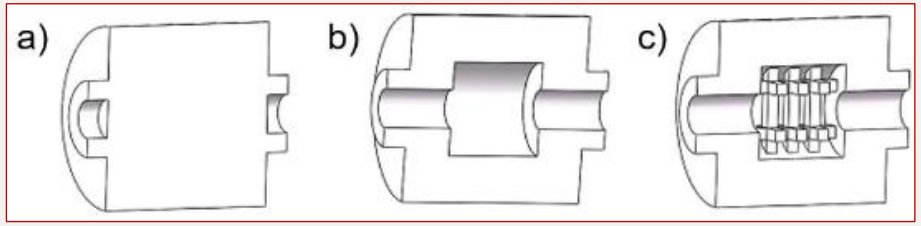

Fig. 3. Scheme of cores: a) solid b) with a cavity c) with a truss structure.

Dana, H.R. & el Mansori, M. (2020). Mechanical characterisation of anisotropic silica sand/furan resin compound induced by binder jet 3D additive manufacturing technology. Ceramics International. 46(11), 17867-17880

Shangguan, H., Kang, J., Deng, C., Hu, Y. & Huang, T. (2017). 3D-printed shell-truss sand mold for aluminium castings. Journal of Material Processing Technology. 250, 247-253.

Molding sands in 3D printing

The most popular in sand 3D printing is no-bake technology, in which molding sand consist of matrix, binder and hardener. Curing is conducted in ambient temperature and is initiated after adding the last component to the mixture.

In foundry plants molds and cores are printed with the use of molding sands bond with **organic binders**.

How about & why inorganic binders?

Halejcio D., Major-Gabryś K. (2024) The use of 3D printed sand molds and cores in the castings production. Archives of Foundry Engineering 24(1), 32-39
Halejcio D., Major-Gabryś K. (2024) Selection of molding sands with inorganic binders for 3D printing - preliminary research, XXX. ročník konference Spolupráce, konference českých, slovenských a polských slévačů : 24.–26.4.2024, Ostravice, Czechia

Foundry molding sands vs. Green Deal policy

Modern industry requires implementation of new innovative technologies. Innovative molding sands technologies must ensure the appropriate technological properties of produced molds and cores and high process efficiency. The high economic efficiency of the process consists of its productivity, including the speed of mold and core making, the prices of raw materials, the costs of production, the costs of knocking-out, finishing and cleaning castings, and the costs of staff, including qualified personnel.

Currently, the dominant factor in the development of molding and core sands technologies is the need to meet high environmental standards. It's even being done at the expense of reducing the technological properties of the materials.

Forsight Technologiczny Odlewnictwa Polskiego, pod redakcją J. Tybulczuka, Instytut Odlewnictwa, ISBN 978-83-88-770-42-5, Kraków, 2009
Liszka K., Dobosz W., The Polish foundry industry is waiting for a revival. Current satus and future forcasts, Przegląd Odlewnictwa, 11-12/2024, 372-378

Foundry molding sands vs. Green Deal policy

Due to mentioned before requirements the molding material technologies that have been used successfully in foundry production processes for decades have been replaced by more environmentally friendly solutions. These include:

- **coal dust,**
- **alcohol protective coatings,**
- **molding sands with ethyl silicate,**
- **furan molding sands,**
- **cold-box technology.**

Thanks to strict environmental regulations and the trend in European industry to move away from harmful technologies over the past few decades, the negative impact of European industry on the environment has been reduced. However, for the European industry to become more environmentally friendly in the future, **it is necessary to implement new innovative technologies**.

Major-Gabryś K., Odlewnicze masy formierskie i rdzeniowe przyjazne dla środowiska (Environmentally friendly foundry molding and core sands), AFE Press, Katowice-Gliwice, 2016

Development trends – own research

In Molding Materials Laboratory of AGH University FFE for many years researchers have been dealing with issues related to the environmentally friendly molding sands. The following technologies, among others, were elaborated:

- **Ecologically friendly molding sands with organic binders.**
- **Green molding sands (sands with clays) with reduced harmfulness.**
- **Molding sands for ablation casting.**
- **Molding sands with sodium silicates with increased knock-out properties.**
- **Molding sands with sodium silicates with better quality of reclaim obtained after their mechanical reclamation.**

Major-Gabryś K., Odlewnicze masy formierskie i rdzeniowe przyjazne dla środowiska (Environmentally friendly foundry molding and core sands), AFE Press, Katowice-Gliwice, 2016
Puzio S., Dobór rodzaju oraz technologii utwardzania mas formierskich przeznaczonych na formy do ablacyjnego odlewania stopów aluminium, praca doktorska AGH, Kraków, 2022
Anwar N., Major-Gabryś K., Jalava K., Orkas J., Effect of additives on heat hardened inorganic solid foundry binder, International Journal of Metalcasting, published online: 02 March 2024

Materials

Table 2. Composition of tested molding sands.

no.	sand matrix	amount [weight part]	binder	amount [weight part]	hardener	amount per binder content [%]
M1	silica sand	100	organic	1.0	hardener	50
M2	silica sand	100	organic$_{3D}$	1.0	hardener$_{3D}$	50
M3	silica sand	100	inorganic A	2.5	Flodur 5	10
M4	silica sand	100	inorganic A$_{3D}$	2.5	Flodur 5	7.35
M5	silica sand	100	inorganic A	2.5	Ixional	10
M6	silica sand	100	inorganic A$_{3D}$	2.5	Ixional	7.35
M7	silica sand	100	inorganic B	2.5	Flodur 5	10
M8	silica sand	100	inorganic B$_{3D}$	2.5	Flodur 5	7.35
M9	silica sand	100	inorganic B	2.5	Ixional	10
M10	silica sand	100	inorganic B$_{3D}$	2.5	Ixional	7.35

sand matrix:

silica sand with the grain size:
0.20/0.16/0.10, where 85% were 0.20 grains

self-hardening organic sands

furfuryl resin	**1.0 p.p.w.**
hardener	**50%**

self-hardening inorganic sands

liquid sodium silicate	**2.5 p.p.w.**
Flodur 5/Ixional	**7.35-10%**

Halejcio D., Major-Gabryś K. (2024) The comparison of chosen - bonded with the use of classical and dedicated for 3D printing furfuryl binder - molding sands' properties as a basis for development a new inorganic system. Archives of Foundry Engineering 2024(1), 32-39

Research Methodology

Viscosity
Conducted with the use of a rheometer.

Contact angle
Tests were conducted statically at 22°C using a high-temperature microscope, holding the sample on a silica plate until the final shape was obtained.

The penetration depth
The measurement was performed on the station shown in Fig. 3.

The molding sand preparation
Conducted in a paddle mixer.
Mixing time of sand and hardener: 60 s
Mixing time with binder: 60 s.

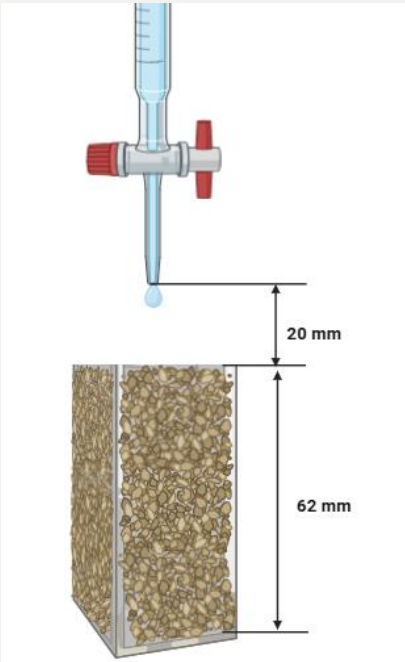

Fig. 3. Scheme of the measuring station of the depth of penetration of the binder into the sand bed.

The kinetic of curing
A sampler with the tested molding sand is placed between the ultrasonic heads and recording the time of passage of the ultrasonic wave through the molding sand sample - porous medium.

Fittings compacting
Test fittings were prepared using the WADAP LUZ-1 vibration compacting device by 9 s.

Hot-distortion parameter
Performed on a DMA device from Multiserw Morek. Tested fittings 114×25.4×6.3 mm are heated with the use of two 500 W halogen filaments to maximum temperature of 900°C.

Anwar N., Major-Gabryś K., Jalava K., Orkas J., Effect of additives on heat hardened inorganic solid foundry binder, International Journal of Metalcasting, published online: 02 March 2024

Conclusions

The following conclusions were drawn based on data analysis and own research:

1. 3D printing enables the production of molds and cores with complex shapes that are impossible to achieve using conventional methods, which can be useful in the production of thin-walled cast iron castings.
2. Strict regulations in the Green Deal policy force the search for new technologies in the field of foundry molding sands.
3. Inorganic binder systems are environmentally friendly technologies and can be an alternative to organic binder systems in modern technologies.
4. The physicochemical properties of commercial inorganic binders can be adapted to the properties of binders dedicated to 3D printing.
5. High reactivity of Ixional binder may be useful in inorganic molding sand systems intended for 3D printing.

Future research will be focused on optimizing the hardening process of molding sands with inorganic binders and finally, their impact on thin-walled castings' properties.

NetCastPL4.0 - NETWORKING -

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Thank you for your attention!

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