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

The use of green molding materials in the production of advanced lightweighting castings

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Faculty of Foundry Engineering

Green Deal policy

In 1972, the first United Nations Conference on the Human Environment was held in Stockholm. It recognized environmental issues as a central international problem and approved the principles of environmental stewardship, including the Stockholm Declaration and the Environmental Action Program. In 1992, the "Earth Summit" was held in Rio de Janeiro. Many important declarations were adopted at the summit, such as Agenda 21, the Rio Declaration, the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity. The above activities on the international arena resulted in the adoption of the following European treaties:

- ✓ In **1972**, the European Council meeting in Paris declared the need for a Community environmental protection policy to accompany economic policy.
- ✓ In **1987**, the Single European Act introduced a new Title VII, "Environment," which provided the first legal basis for a common environmental policy.
- ✓ In **1993**, the Maastricht Treaty made the environment (Title XVI) an official EU policy area.
- ✓ In **1999**, Article 3c of the Treaty of Amsterdam mandated the integration of environmental protection into all EU sectoral policies.
- ✓ In **2007**, climate change and sustainable development became a priority under the Treaty of Lisbon.

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https://www.europarl.europa.eu/factsheets/pl/sheet/71/polityka-ochrony-srodowiska-ogolne zasady-i-podstawowe-ramy; access 19-02-2025

Green Deal policy

The EU environmental policy is based on **4 principles**:

- **Precaution**: if an action or policy may cause damage to the environment or to public health and there is a lack of scientific certainty about its effects, the action should not be applied until further evidence is provided;
- **Prevention**: the aim is to prevent environmental damage rather than just reacting to it. This requires preventive measures to anticipate and avoid environmental damage.
- **Removal of pollution at the source**: if damage has already occurred, the polluter is obliged to take appropriate measures to remedy it and to cover the costs.
- **"Polluter pays":** if damage has already occurred, the polluter is obliged to take appropriate measures to remedy it and to cover the costs. This principle is implemented in the Environmental Liability Directive, which aims to prevent or otherwise remedy damage to the environment, protected species and natural habitats, and damage to water and soil .

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https://www.europarl.europa.eu/factsheets/pl/sheet/71/polityka-ochrony-srodowiska-ogolne zasady-i-podstawowe-ramy; access 19-02-2025

Green Deal policy

The new regulation is the **CBAM** (Carbon Border Adjustment Mechanism) – the so-called “carbon tax”, which came into force in the EU on October 1, 2023. It is a mechanism for adjusting prices at EU borders, taking into account CO_2 emissions. The aim of this tax is to introduce mechanisms to achieve the European Union's goal of climate neutrality by 2025 at the latest. The **CBAM**, implemented in accordance with the “green deal” policy, is based on the requirements set out in the following legal acts:

- Regulation 2023/956 of the European Parliament and of the Council (EU) of May 10, 2023 establishing a mechanism for adjusting prices at borders taking into account CO_2 emissions (entry into force 05/17/23);

- Executive Regulation 2023/1773 of Commission (EU) of August 17, 2023, laying down rules for the application of Regulation 2023/956 of the European Parliament and of the Council (EU) as regards the reporting obligations for the purposes of the border price adjustment mechanism including CO_2 emissions during the transition period (entry into force 09/16/23).

Liszka K., Dobosz W., Polski przemysł odlewniczy czeka na ożywienie. Stan aktualny i prognozy na przyszłość., Przegląd Odlewnictwa, 11-12/2024, 372-378

Green Deal policy vs. foundry molding sands

Ensuring the appropriate technological properties of the mold and core and high process efficiency are very important conditions for the development of molding sands. 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 employing workers, including qualified personnel.

The need to meet high environmental standards is nowadays the dominant factor in the development of molding and core technology, which is 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

Molding sands for light-weight castings

Among the numerous classifications of molding compounds, the classification proposed by P. Jelinka stands out for its simplicity and substantive justification.

This classification divides compounds into four generations depending on the type of binding material:

- ✓ Generation I – molding sands in which clays are used as binding materials,
- ✓ Generation II – molding sands in which the binding material is a binder,
- ✓ Generation III – molding sands without binding materials, also known as physically bound sands,
- ✓ Generation IV – molding sands bound by biotechnological factors.

Generation II molding compounds, i.e., compounds bound with binders, are most commonly used in casting processes. This is due to their high technological properties, but also to their versatility. They can be used for both molds and cores production.

Lewandowski J.L., Tworzywa na formy odlewnicze, Wydawnictwo Akapit, Kraków, 1997. (in Polish)
Dobosz St., M., Woda w masach formierskich i rdzeniowych, WN Akapit, Kraków, 2006. (in Polish)
Major-Gabryś K., Odlewnicze masy formierskie i rdzeniowe przyjazne dla środowiska, Archives of Foundry Engineering Press, Katowice-Gliwice, 2016
Jelinek P., Pojivove soustavy slevarenskych formovacich smesi, Ostrava, 2004. (in Czech)

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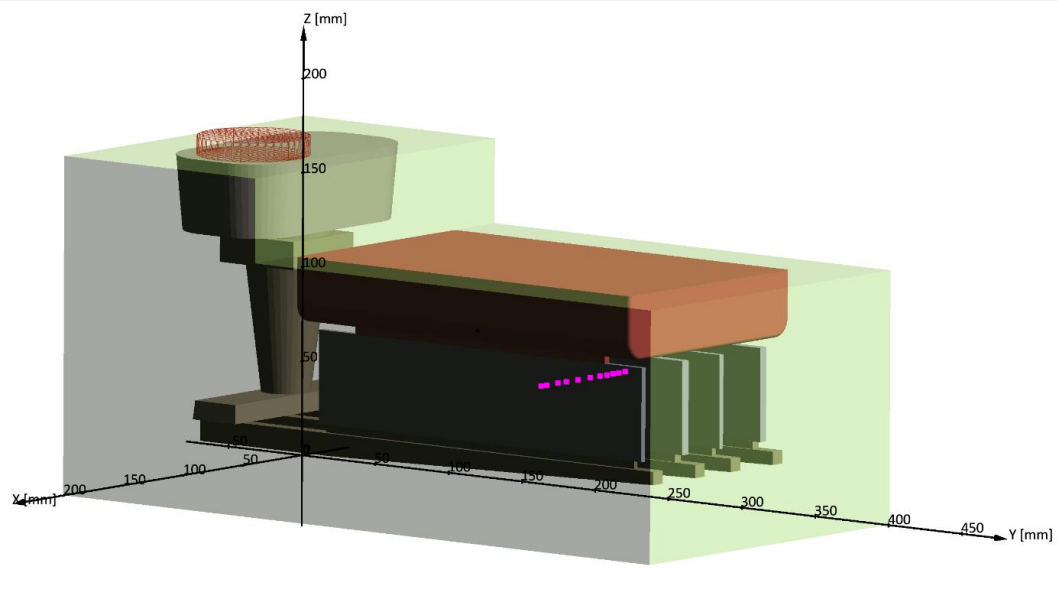
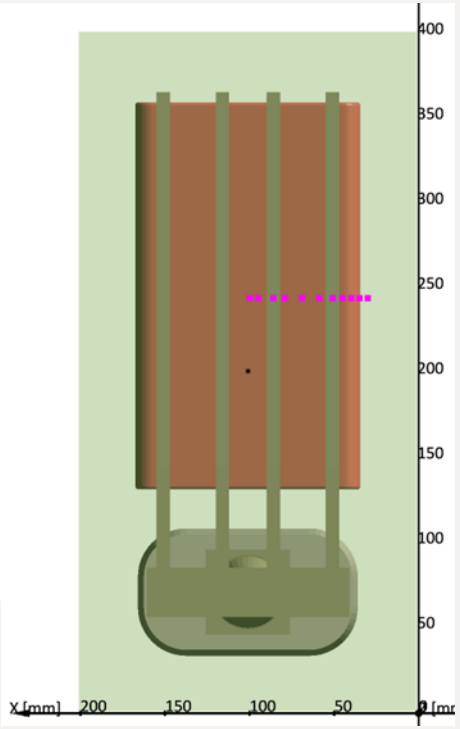
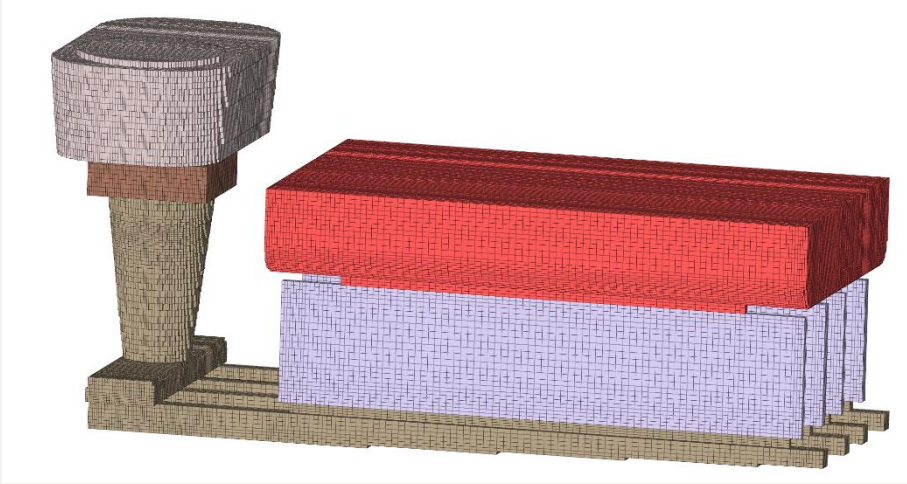
Design of mold for thin-walled castings







ICCME25

Organic molding sands chosen for tests

Two types of self-hardening organic molding compounds used for disposable molds and cores in the production of cast iron and non-ferrous metal castings were selected for testing. The most commonly used are compounds with furfuryl alcohol-modified resin and, as an alternative to them, slightly less harmful to the environment, compounds with phenolic resin cured with esters.

Molding sand symbol	furfuryl resin, p.p.w.	hardener, % to resin content
furfuryl resin-0.7/hardener-50%	0.7	50
furfuryl resin-1.0/hardener-50%	1.0	50
furfuryl resin-1.5/hardener-50%	1.5	50
furfuryl resin-2.0/hardener-50%	2.0	50

Molding sand symbol	phenolic resin, p.p.w.	hardener1, % to resin content	hardener2, % to resin content
phenolic resin-1.5/hardener1-5%	1.5	5	
phenolic resin-1.5/hardener1-10%	1.5	10	
phenolic resin-1.5/hardener1-25%	1.5	25	
phenolic resin-2.0/hardener1-10%	2.0	10	
phenolic resin-2.0/hardener1-15%	2.0	15	
phenolic resin-2.0/hardener1-25%	2.0	25	
phenolic resin-1.5/hardener2-25%	1.5		25
phenolic resin-2.0/hardener2-10%	2.0		10
phenolic resin-2.0/hardener2-15%	2.0		15
phenolic resin-2.0/hardener2-25%	2.0		25
phenolic resin-2.5/hardener2-25%	2.5		25

Major-Gabryś K., Drożyński D., Selection of molding sands for thin-walled cast iron castings, including testing of their selected properties, 2025, https://repo.agh.edu.pl/handle/AGH/115009

Inorganic molding sands chosen for tests

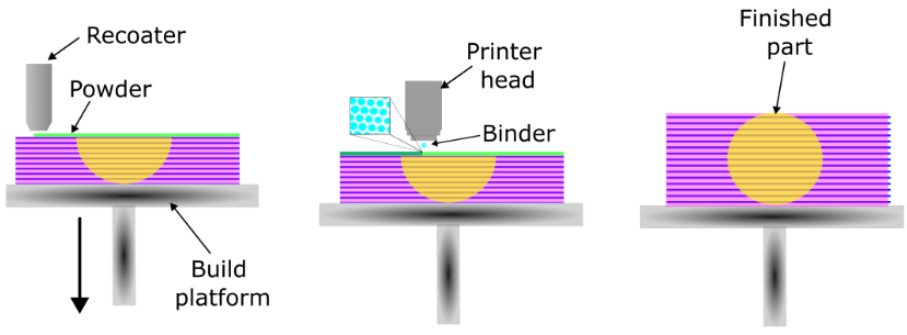
Two types of self-hardening molding compounds with inorganic binders used for disposable molds and cores in the production of cast iron castings were selected for testing. The tests were carried out on compounds with R145 water glass hardened with Flodur hardener (Floster technology) and compounds with aluminosilicate binder.

Molding sand symbol	water glass R145, p.p.w.	hardener , % to binder content
water glass R145-2.0/hardener-10%	2.0	10
water glass R145-3.0/hardener-5%	3.0	5
water glass R145-3.0/hardener-10%	3.0	10
water glass R145-3.0/hardener-15%	3.0	15
water glass R145-4.0/hardener-10%	4.0	10

Molding sand symbol	aluminosilicate, p.p.w.	hardener , % to binder content
aluminosilicate-2.0/hardener-5%	2.0	5
aluminosilicate-2.0/hardener-10%	2.0	10
aluminosilicate-2.0/hardener-15%	2.0	15
aluminosilicate-2.5/hardener-10%	2.5	10
aluminosilicate-3.0/hardener-10%	3.0	10

Major-Gabryś K., Drożyński D., Selection of molding sands for thin-walled cast iron castings, including testing of their selected properties, 2025, https://repo.agh.edu.pl/handle/AGH/115009

Mold produced in additive manufacturing – 3D printed



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

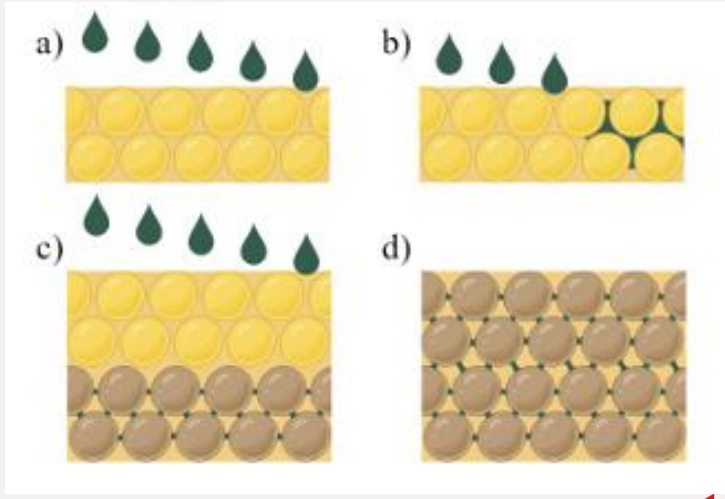
Produced in binder jetting (3D printing) technology sand molds and cores are succesfully used in the production of castings and their number constantly increases. The technology enables the production of molds and cores with complex shapes that are impossible to achieve using conventional methods, which 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%

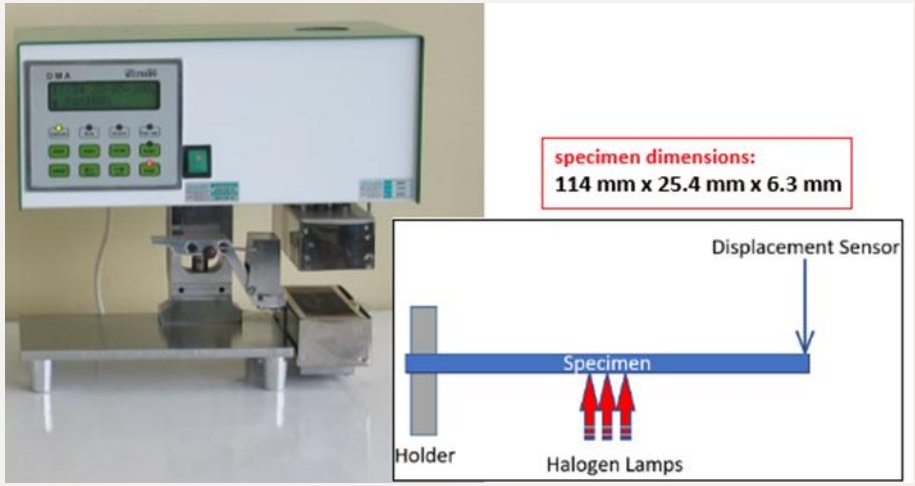


Printing process in binder jetting 3D system: a) droplets of liquid binder are applied to layer of matrix; b) binder surrounds sand grains; c) droplets of binder applied to new layer of matrix; d) matrix grains connected by resin bridges.

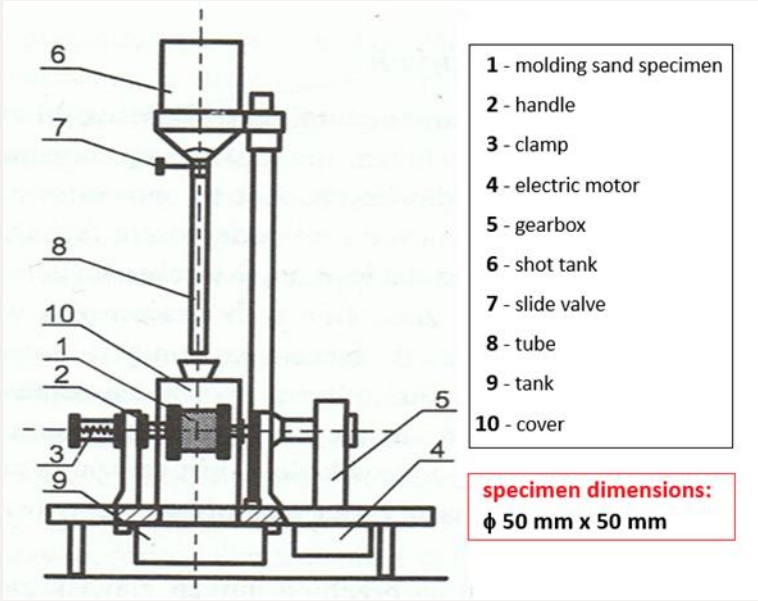
Jandyal, A., Chaturvedi, I., Wazir, I., Raina, A. & Ul Haq,M.I. (2022) 3D printing – A review of processes, materials and applications in industry 4.0. Sustainable Operations and Computers. 3, 33-42. DOI: 0.1016/j.susoc.2021.09.004
Upadyay M., Sivarupan T. & El Monsori M. (2017) 3D rapid for sand casting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

Tests of molding sands chosen for light-weighting castings – what was tested

- **Tensile strength, bending strength, permeability & friability**
- **Bench life**
- **Hot distortion**
- **Thermal analysis**
- **Gas emission tests**



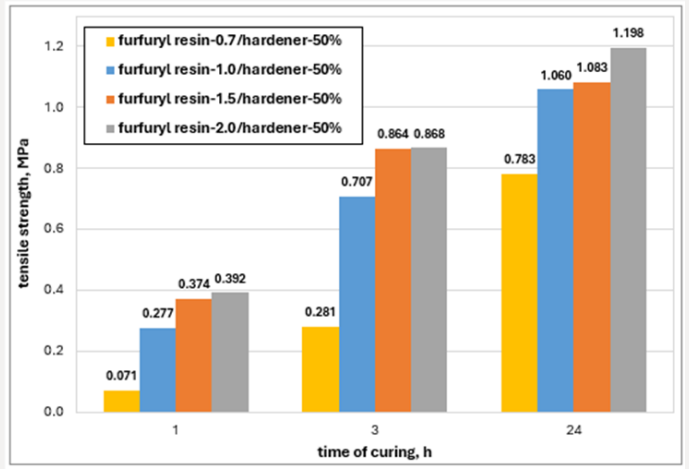
Prototype device for measuring molding sands deformation at elevated temperatures, type DMA with schematic diagram of the Hot Distortion Test, adapted from [5, 19].

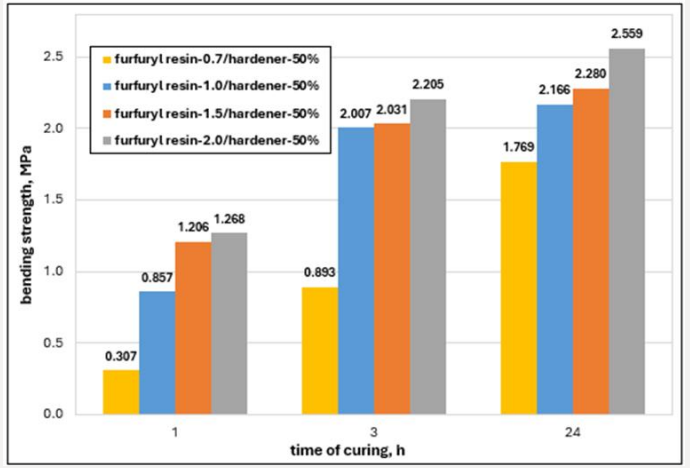


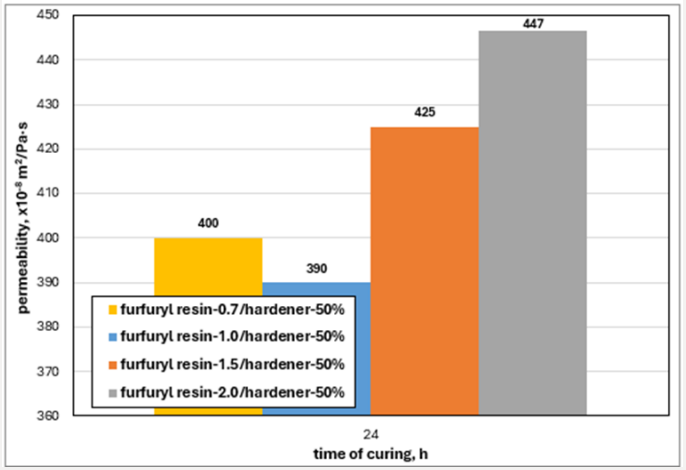
The scheme of an apparatus for friability test designed in Poland by the HSW S.A. company [18].

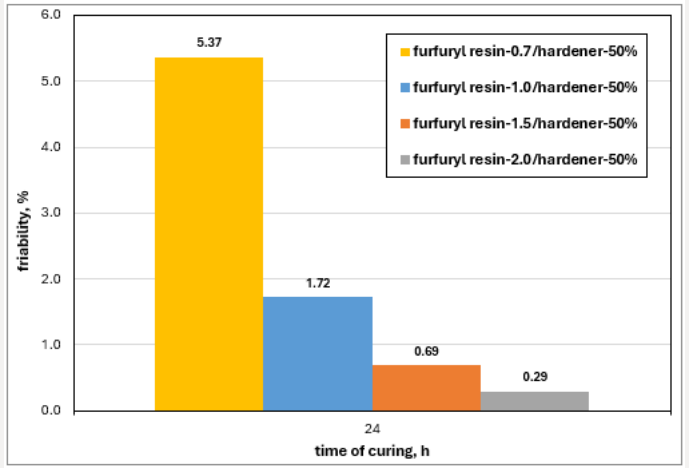
Anwar N., Major-Gabryś K., Jalava K., Orkas J., Effect of additives on heat hardened inorganic solid foundry binder, International Journal of Metalcasting, Volume 19, Issue 1, 2025, 129-144, DOI: 10.1007/s40962-024-01277-w
Lewandowski J.L., Materiały formierskie. Laboratorium, Skrypty Uczelniane nr 1008 Akademii Górniczo-Hutniczej im. S. Staszica w Krakowie Kraków, 1986.
Jakubski J., Skłonność wybranych mas formierskich do deformacji przy wysokiej temperaturze, Praca Doktorska AGH, Kraków, 2006. (in Polish)

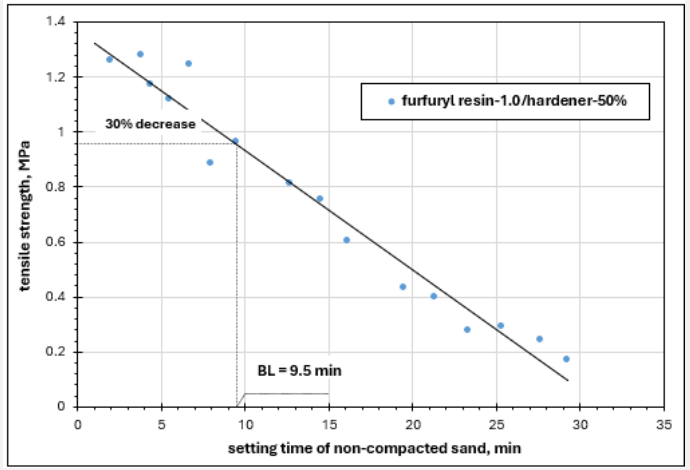
Molding sands with furfuryl resin – chosen properties

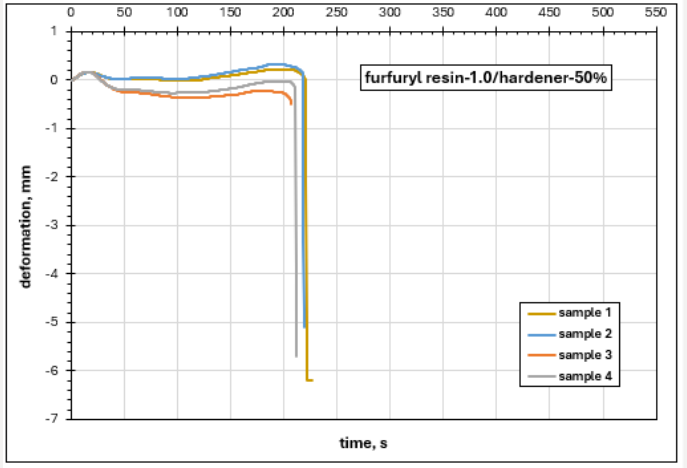












Major-Gabryś K., Drożyński D., Selection of molding sands for thin-walled cast iron castings, including testing of their selected properties, 2025, https://repo.agh.edu.pl/handle/AGH/115009

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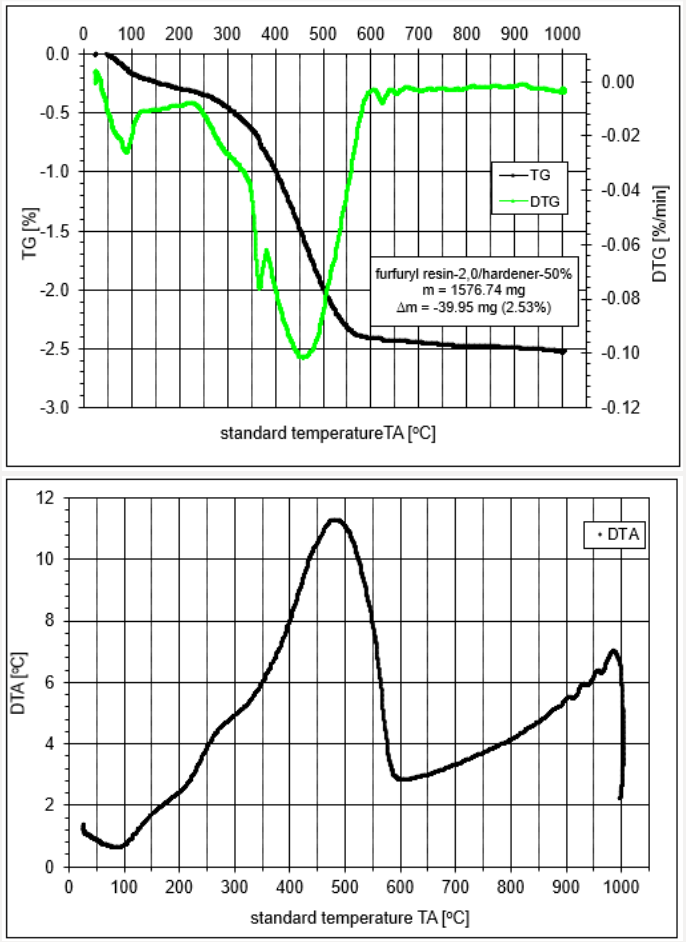
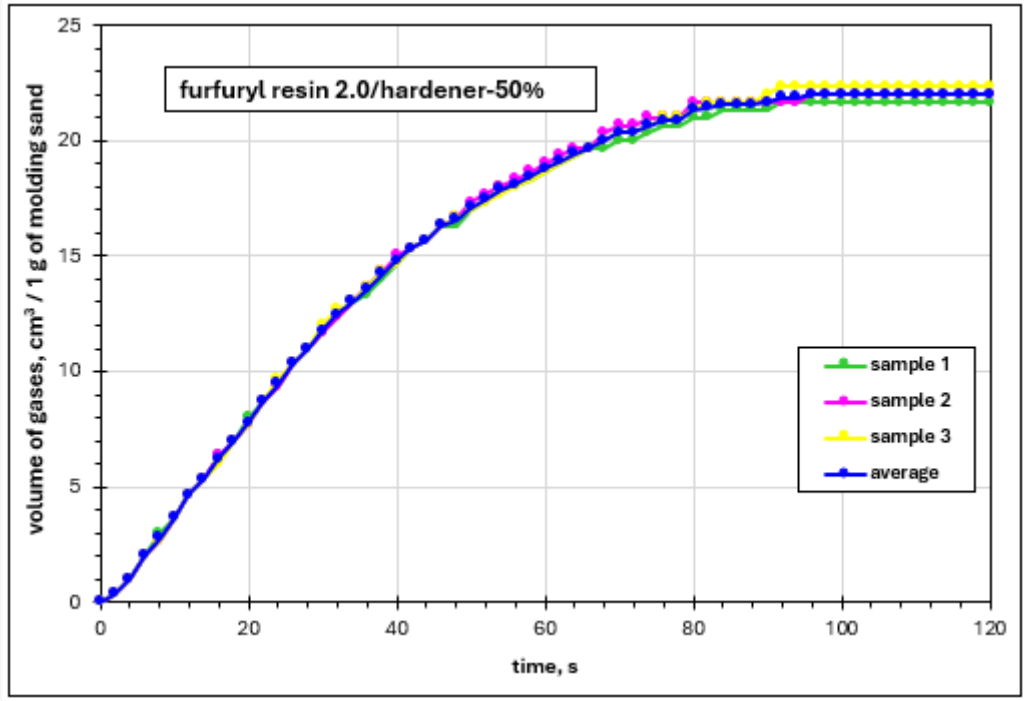
Molding sands with furfuryl resin



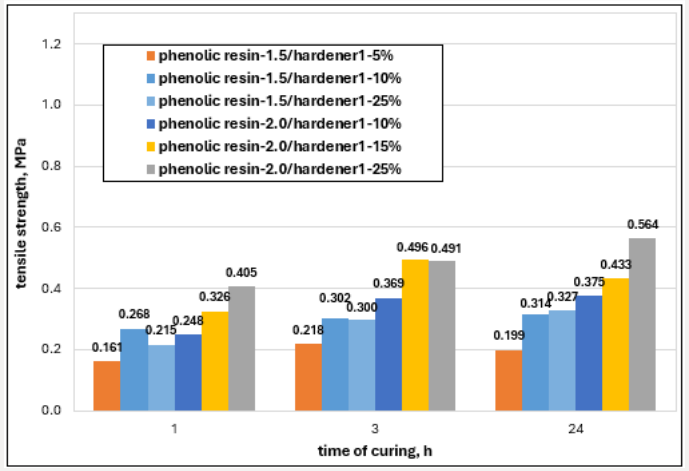
Thermal degradation (thermogravimetric) tests of chosen molding sand with furfuryl resin

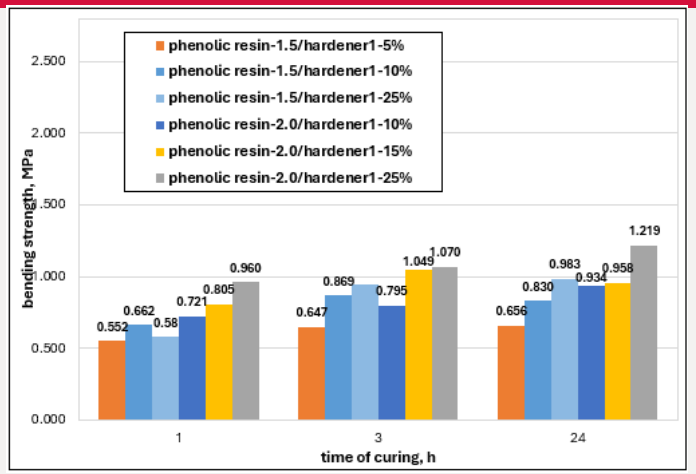


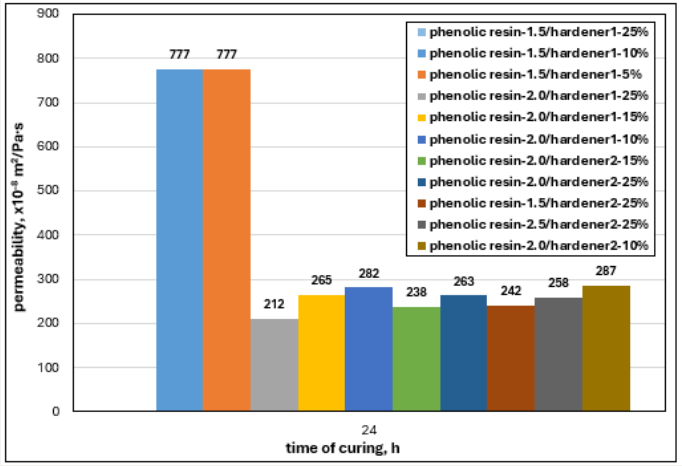
Gas emission results for molding sand with 2.0 p.p.w. of furfuryl resin.

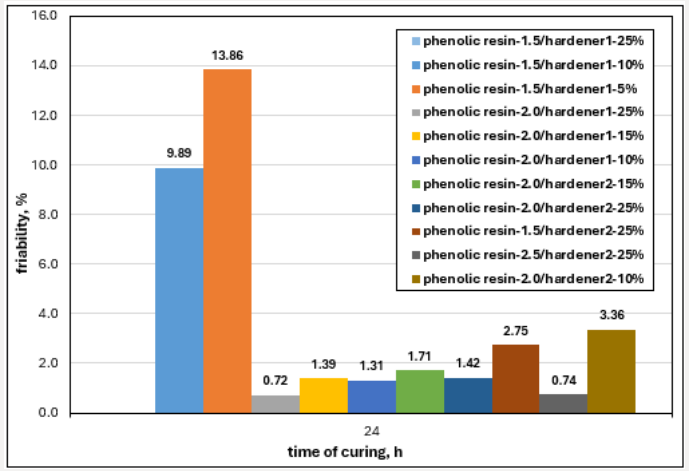
Major-Gabryś K., Drożyński D., Selection of molding sands for thin-walled cast iron castings, including testing of their selected properties, 2025, https://repo.agh.edu.pl/handle/AGH/115009

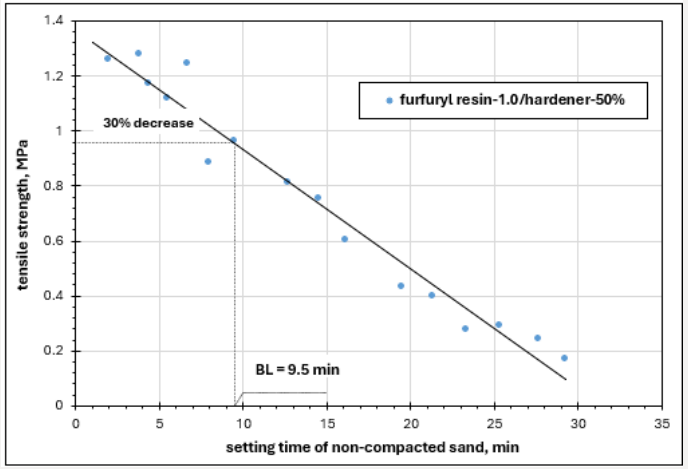
Molding sands with phenolic resin

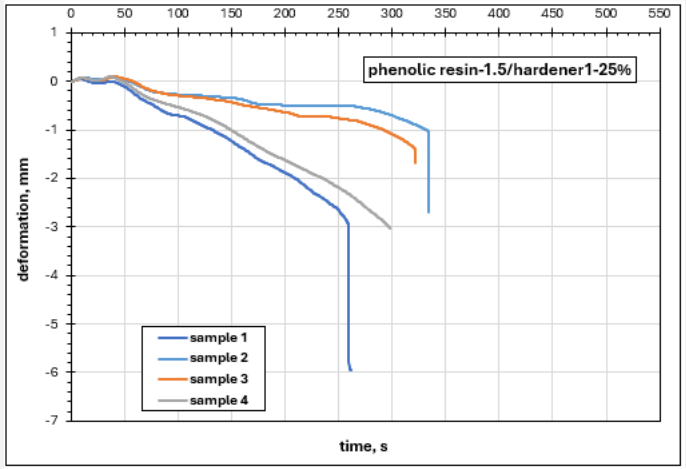












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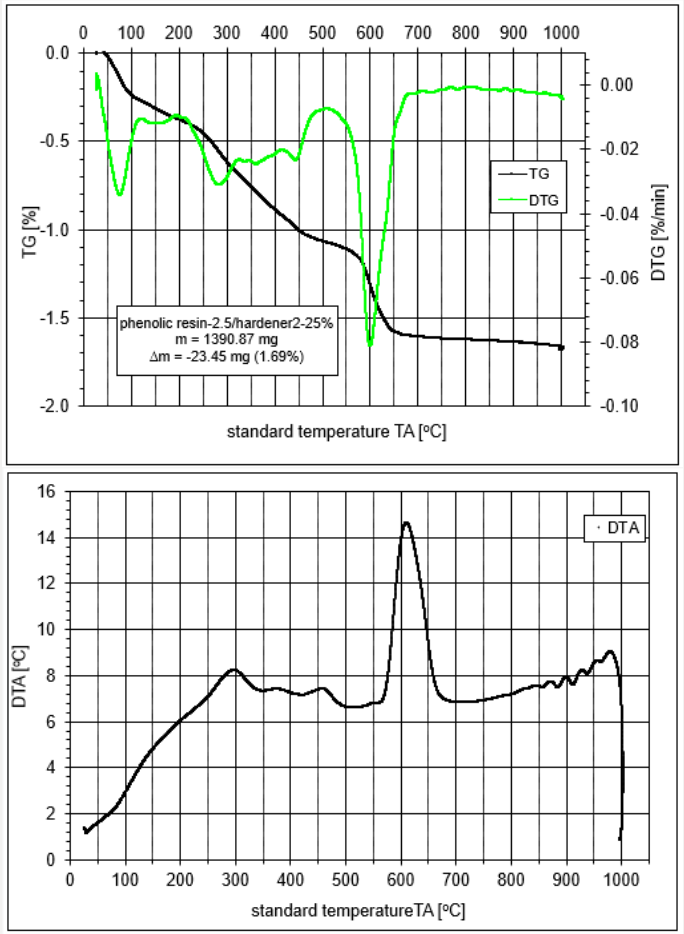
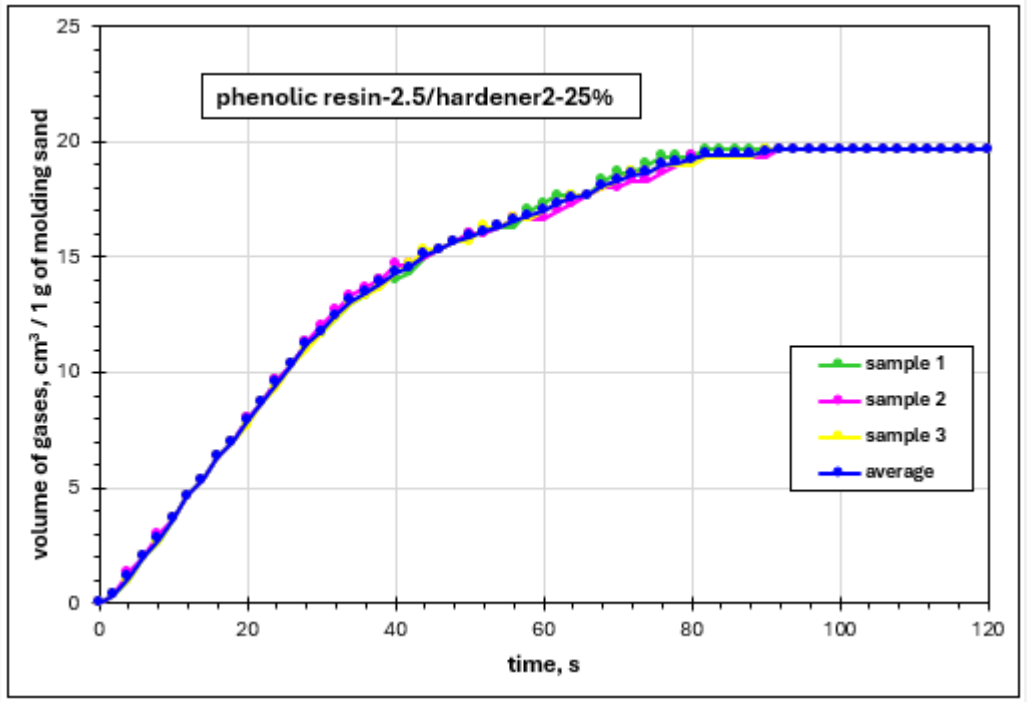
Molding sands with phenolic resin



Thermal degradation (thermogravimetric) tests of chosen molding sand with phenolic resin.



Gas emission results for molding sand with 2.5 p.p.w. of phenolic resin.

Major-Gabryś K., Drożyński D., Selection of molding sands for thin-walled cast iron castings, including testing of their selected properties, 2025, https://repo.agh.edu.pl/handle/AGH/115009

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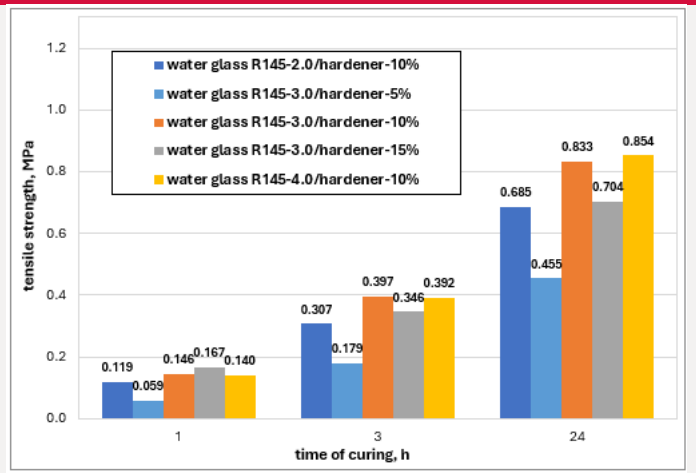
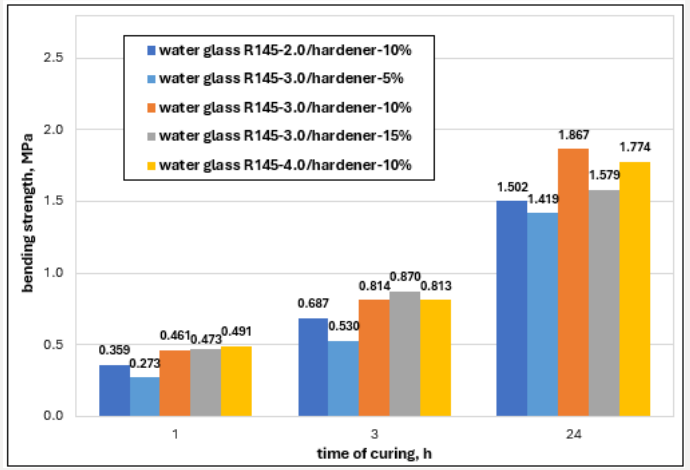
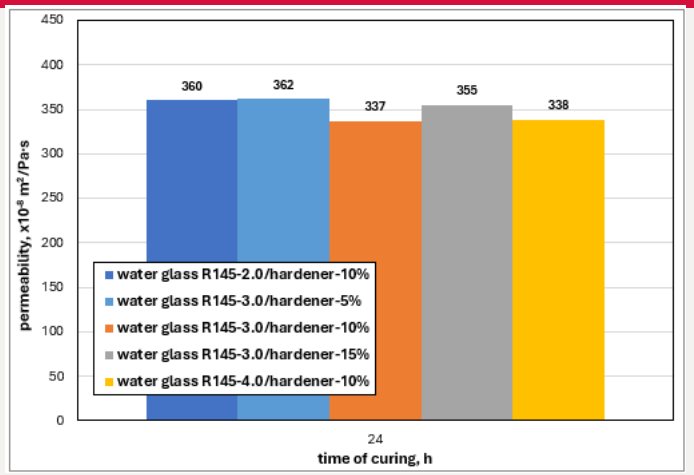
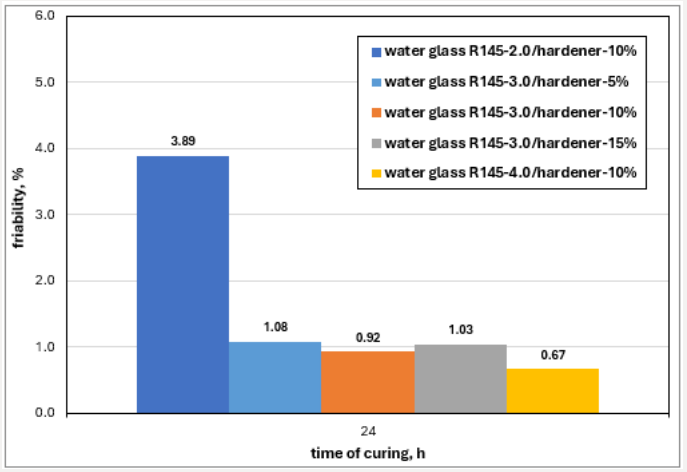
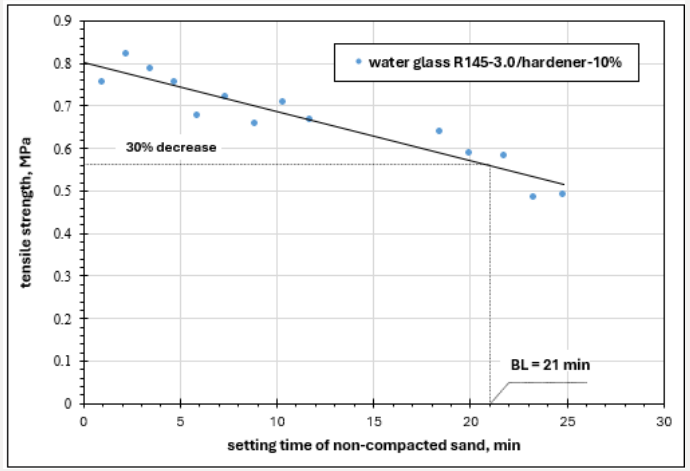
Molding sands with hydrated sodium silicate (water glass)

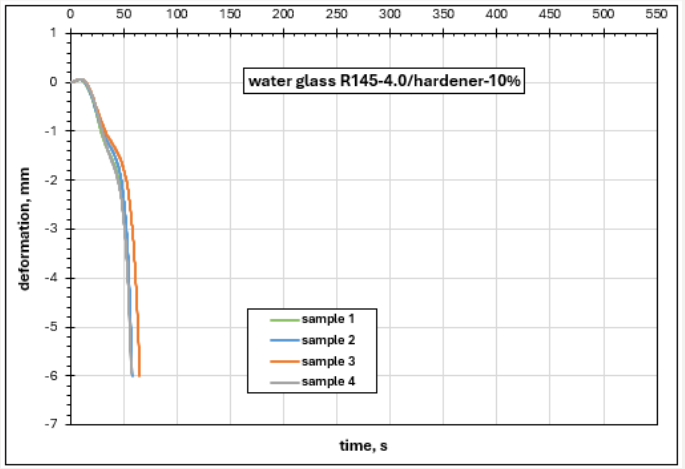












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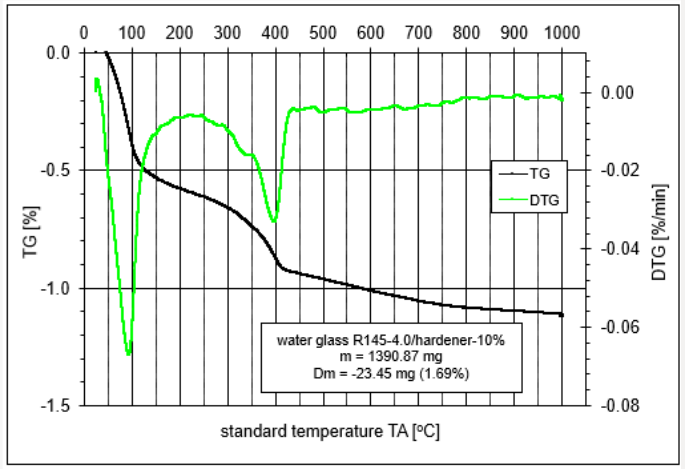
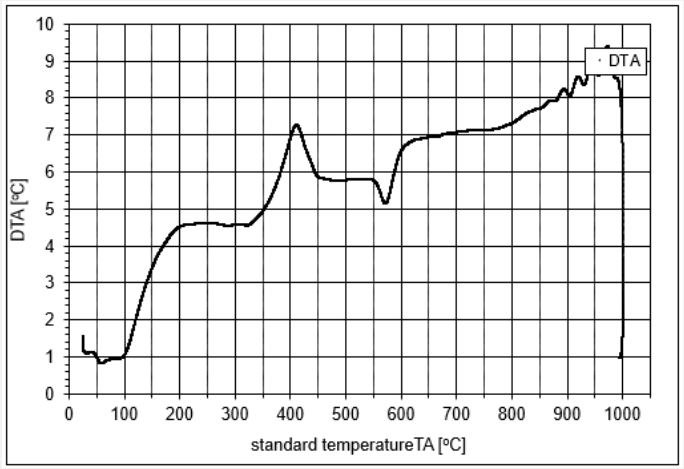
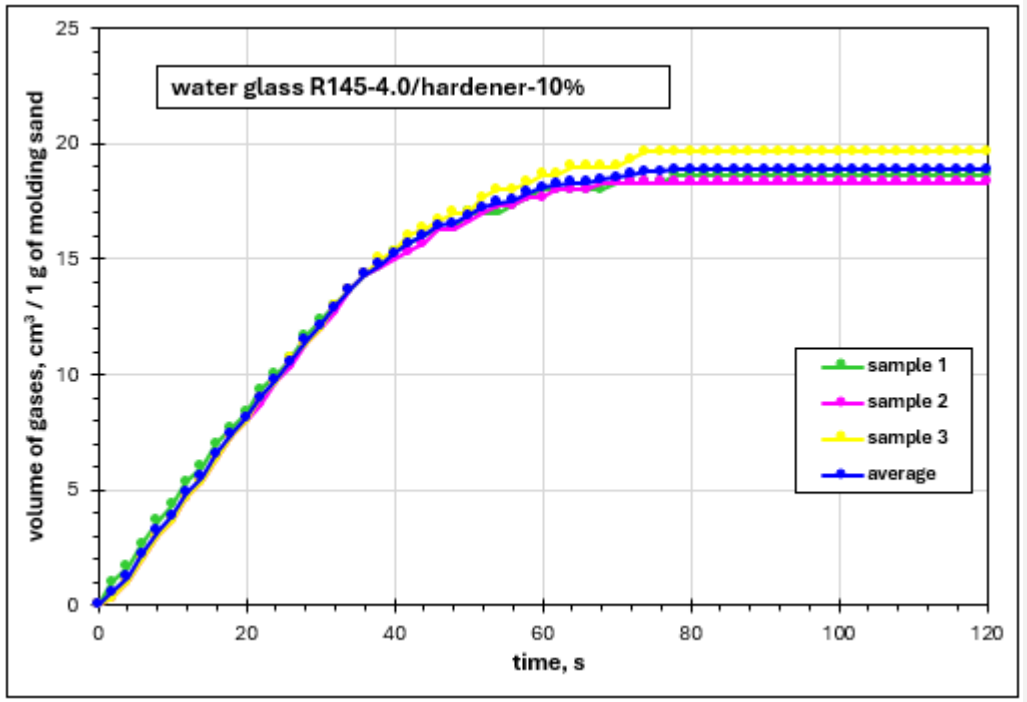
Molding sands with hydrated sodium silicate (water glass)





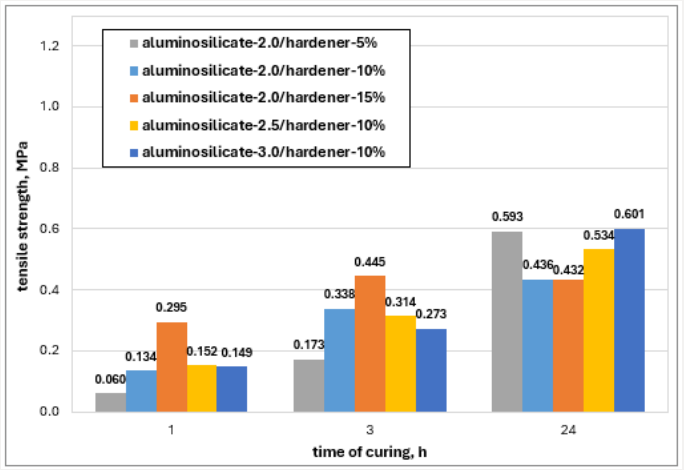
Thermal degradation (thermogravimetric) tests of chosen molding sand with water glass.

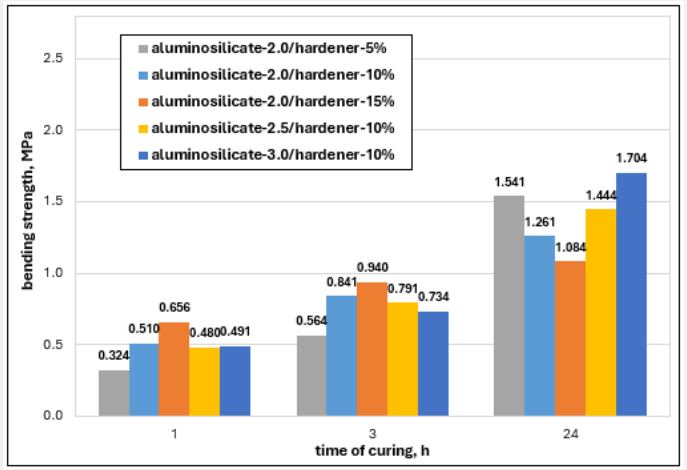


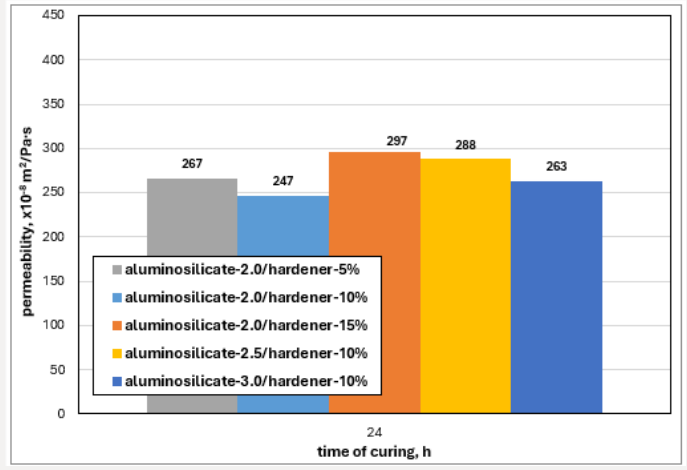
Gas emission results for molding sand with 4.0 p.p.w. of water glass.

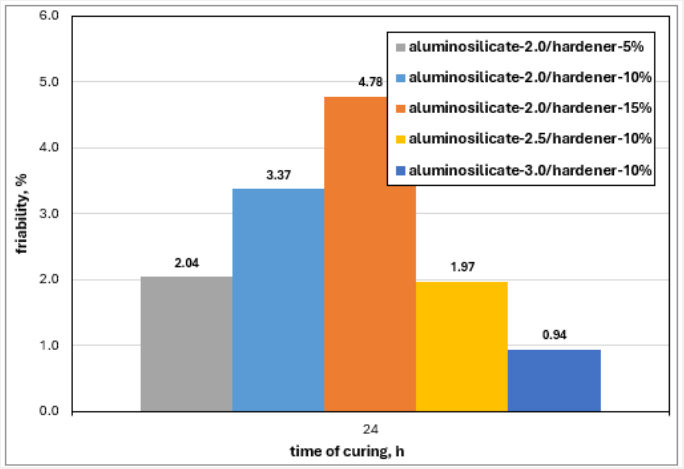
Major-Gabryś K., Drożyński D., Selection of molding sands for thin-walled cast iron castings, including testing of their selected properties, 2025, https://repo.agh.edu.pl/handle/AGH/115009

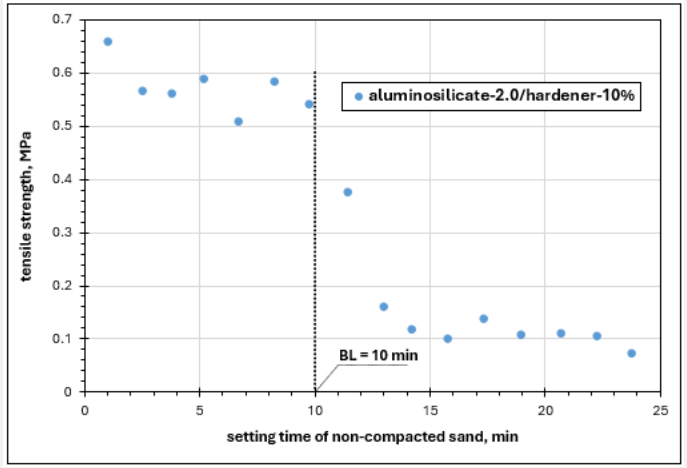
Molding sands with aluminosilicate (geopolymer)

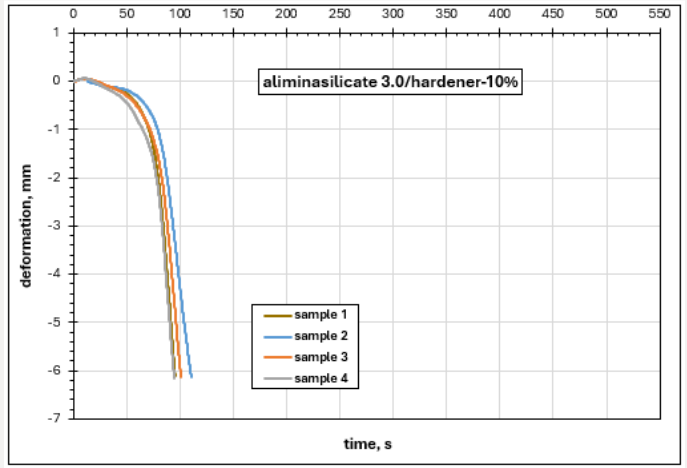






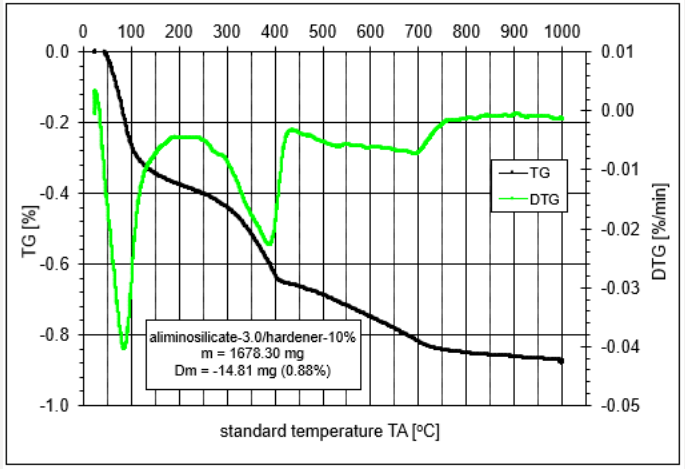


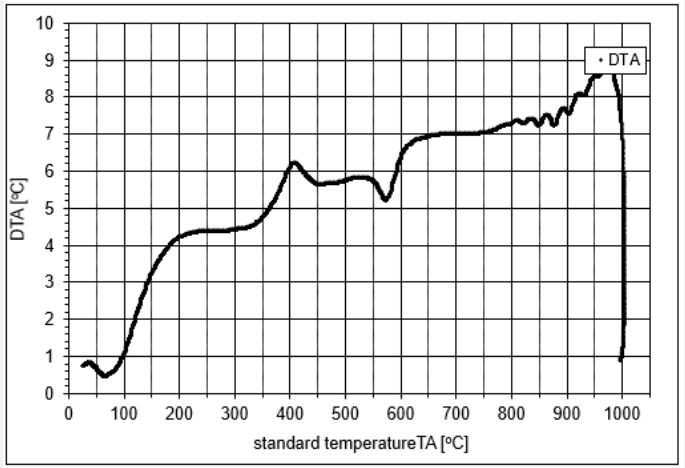




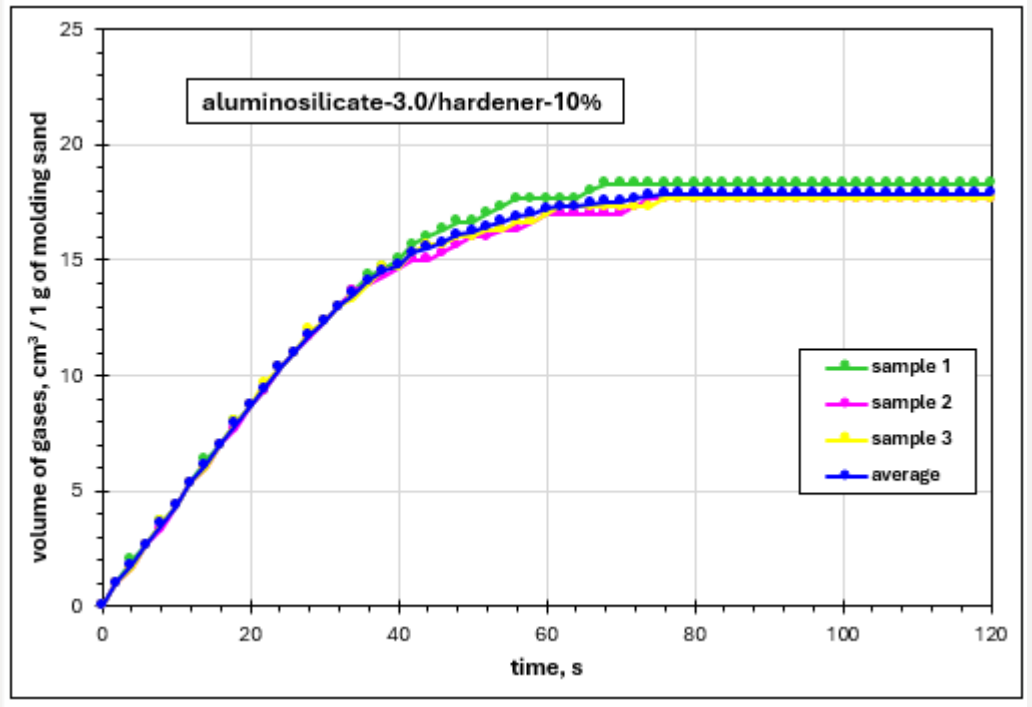
Major-Gabryś K., Drożyński D., Selection of molding sands for thin-walled cast iron castings, including testing of their selected properties, 2025, https://repo.agh.edu.pl/handle/AGH/115009

Molding sands with aluminosilicate (geopolymer)





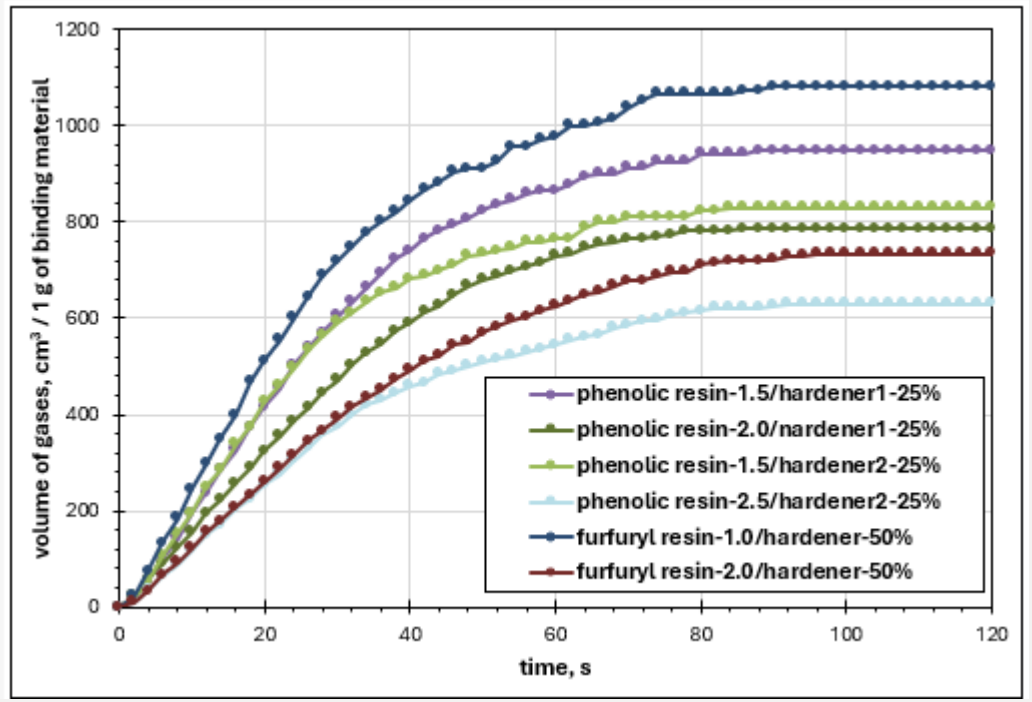
Thermal degradation (thermogravimetric) tests of chosen molding sand with geopolymer.



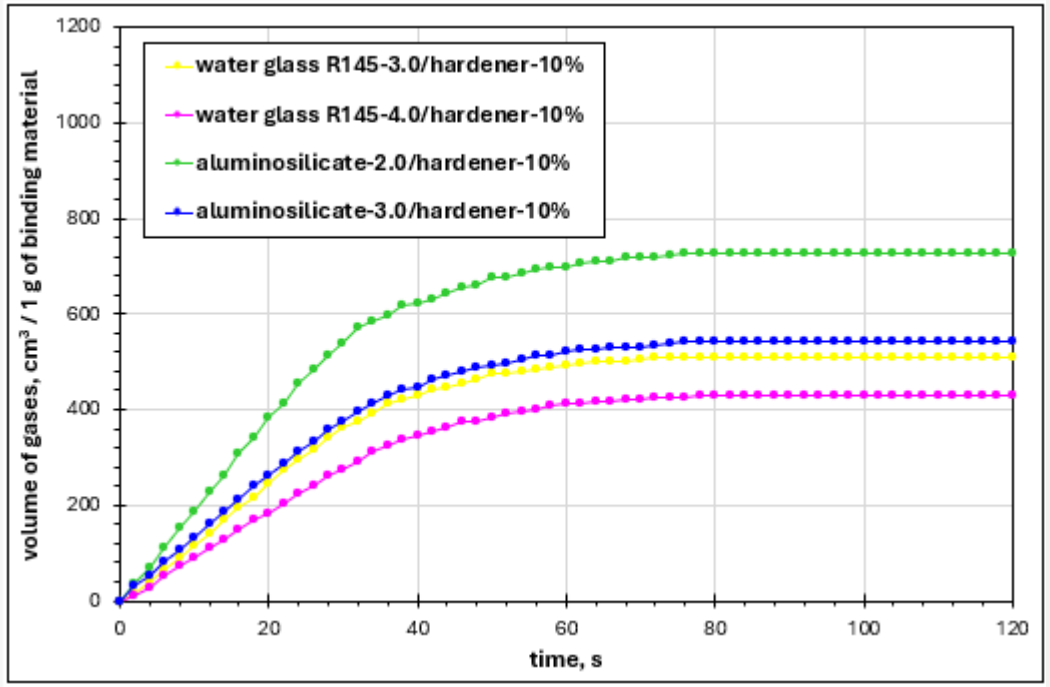
Gas emission results for molding sand with 3.0 p.p.w. of geopolymer.

Major-Gabryś K., Drożyński D., Selection of molding sands for thin-walled cast iron castings, including testing of their selected properties, 2025, https://repo.agh.edu.pl/handle/AGH/115009

Gas emission tests – the emission per 1g of binding material



Gas emission results for volume of gases emitted from 1 g of binding material used in molding sands with organic binders.



Gas emission results for volume of gases emitted from 1 g of binding material used in molding sands with inorganic binders.

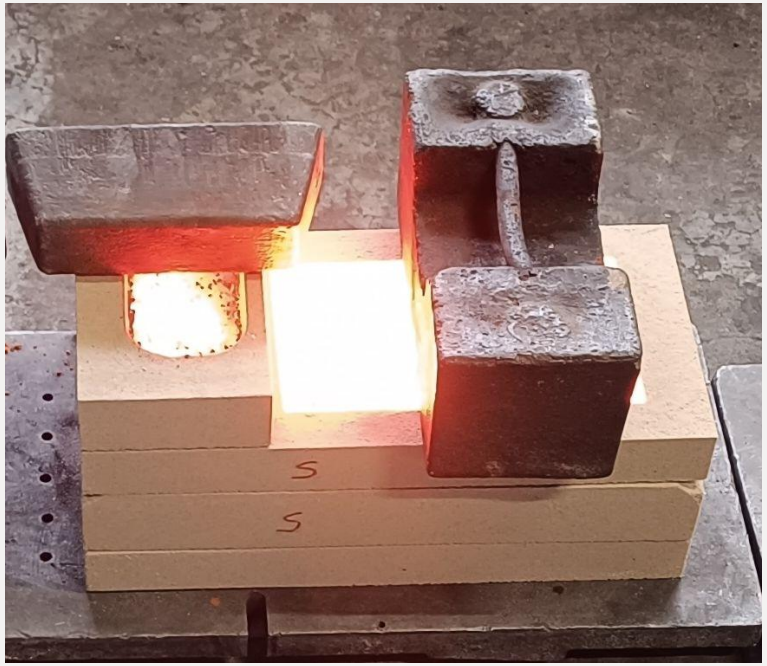
Major-Gabryś K., Drożyński D., Selection of molding sands for thin-walled cast iron castings, including testing of their selected properties, 2025, https://repo.agh.edu.pl/handle/AGH/115009

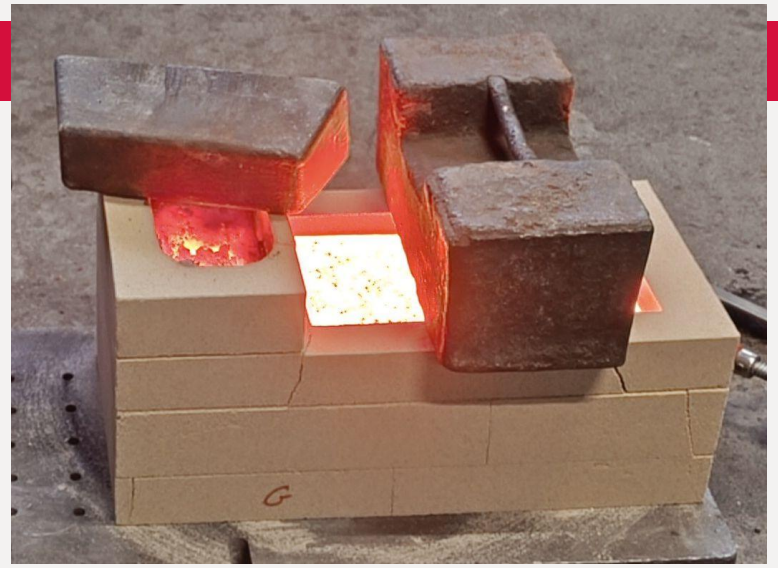
Molding sands chosen for the production of molds for thin-walled castings

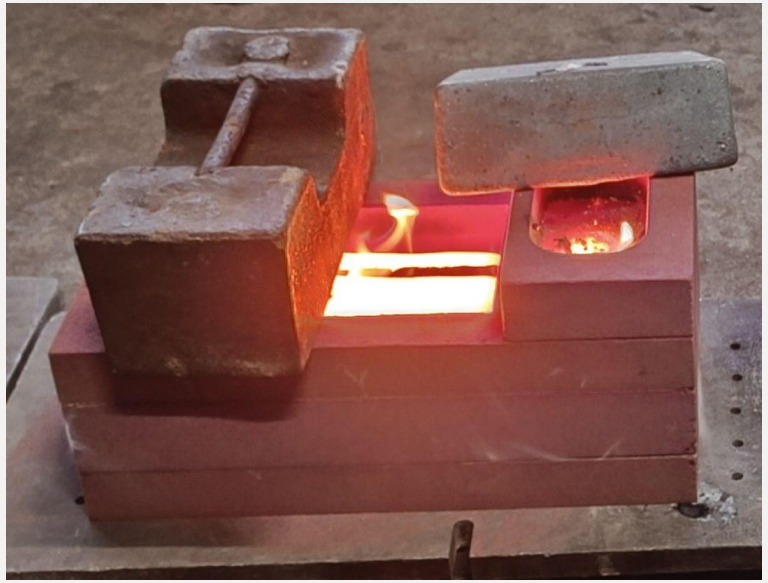
Molding sands chosen for the production of molds for thin-walled castings.

Mold no.	molding sand type	quarz sand, p.p.w.	binder, p.p.w.	hardener, % to resin content
MOLD 1	furfuryl resin-1.0/hardener-50%	100	2.0	50
MOLD 2	phenolic resin-2.5/hardener2-25%	100	2.5	25
MOLD 3	water glass R145-3.0/hardener-5%	100	3.0	10
MOLD 4	aluminosilicate-2.0/hardener-10%	100	2.0	10
MOLD 5	3D printed furan mold			

Molds pouring







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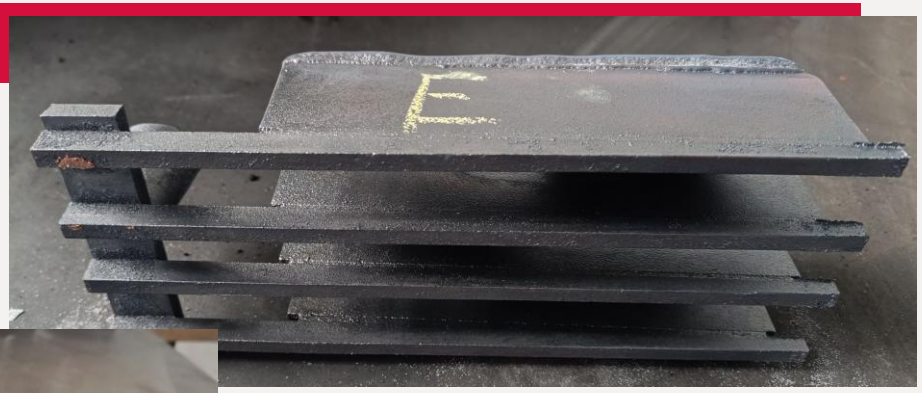
Molding sands with furfuryl resin



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Conclusions

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

1. All molding sands selected for testing are characterized by sufficient strength, good permeability, and adequate resistance to mechanical damage (abrasion resistance) from a practical point of view.
2. Thermal degradation tests showed mass losses in samples depending on the content and type of binder.
3. Gas emission tests showed lower gas emission per gram of binder material in the case of mixtures with inorganic binders..
4. In the next stage of the work, spheroidal cast iron castings were made from the molding compounds selected for testing. Castings were also made in a similar mold produced using 3D printing technology. The thin-walled castings obtained were subjected to testing.

The research is co-financed within NetCastPL4.0 project. The project is funded by the European Union under the Horizon Europe programme, Grant Agreement No. 101159771.

Thank you for your attention!

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