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

The effect of binder type (including inorganic binder designed for 3D printing) on the properties of the surface layer of castings made from aluminium alloys

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21.04.2026 Sulisław Palace, Grodków, Poland

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Introduction

The technology of 3D printing for the production of sand molds and casting cores is increasingly being used in industry for manufacturing castings from non-ferrous metal alloys. [1-4] Among additive manufacturing methods, 3D printing is considered one that does not require further processing after the printing process is completed. Currently, additive manufacturing techniques have become part of Industry 4.0 and one of the tools for rapid prototyping. [2-5]

Figure 1.Casting made of aluminum alloy in a mold produced using binder jetting technology. [6]

In 3D printing processes, quartz sand is typically used as the base material, with grain sizes ranging from 0.14 to 0.25 mm, and deposited in layers 0.28 to 0.50 mm thick. The binding agent is most commonly furfuryl resin, usually applied in amounts of 1–3%, though levels as high as 8% have also been reported. At present, research is also being conducted on the **development of inorganic binders for 3D printing applications**, with the aim of improving environmental performance and expanding their potential for future industrial use. [6, 8-10]

Materials and methodology

Table 1. Composition of molding sands used for tests.

	Sand Matrix	Amount [p.p.w.]	Binder	Amount [p.p.w.]	Hardener	Amount [%]*
M1	Silica sand	100	FK	1.0	dedicated	50.00
M2	Silica sand	100	A	2.5	Flodur 5	10.00
M3	Silica sand	100	A3D	2.5	Flodur 5	7.35

*** in relation to the amount of binder**

FK - classic furfuryl resin

A - inorganic commercial binder based on sodium silicate

A3D - inorganic commercial binder based on sodium silicate modified for future use in 3D printing

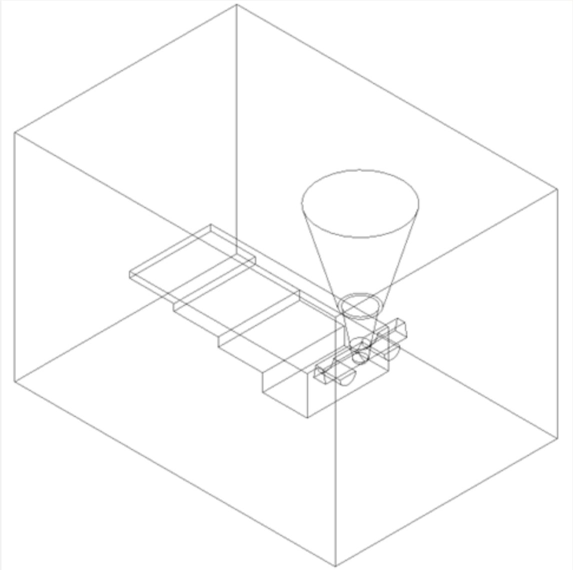

Figure 2. Design of a model and gating system intended for production using 3D printing technology.

Table 2. The chemical composition analysis of the examined aluminium alloy.

Element	Si	Fe	Cu	Mn	Mg	Ti	Al
Amount [% weight]	7.49	0.13	0.02	0.01	0.48	0.03	balance

Computer simulation process in MagmaSOFT 6.1:

- pouring temperature 750 [°C];
- pouring process completed when the mold cavity was completely filled;
- crystallization process completed when the temperature reached 500 [°C].

Gas emission

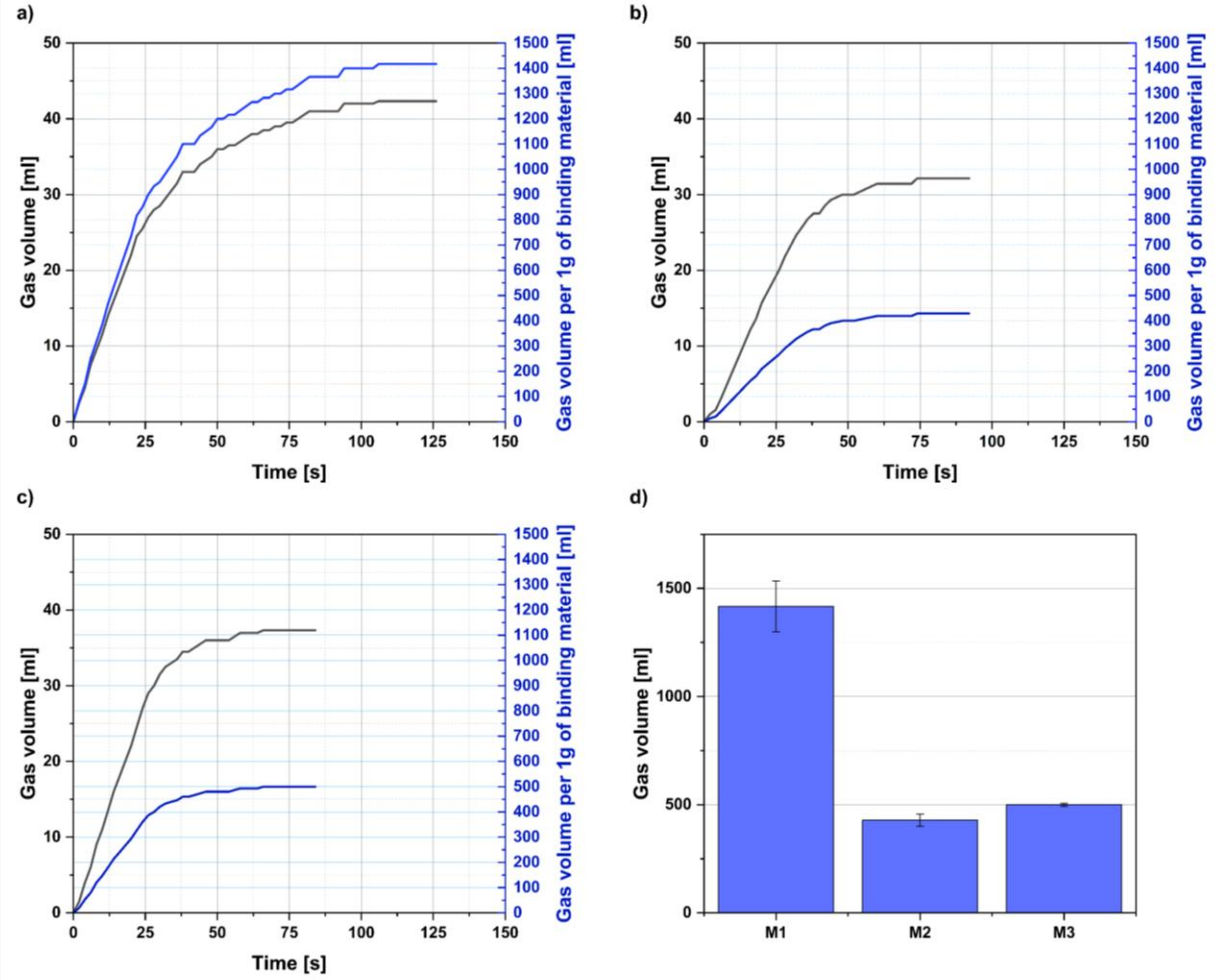

Figure 3. Results of gases emission tests with values calculated per 1g of molding material (binder + hardener). a) M1, b) M2, c) M3 d) final result

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Simulation of casting, cooling and solidification process

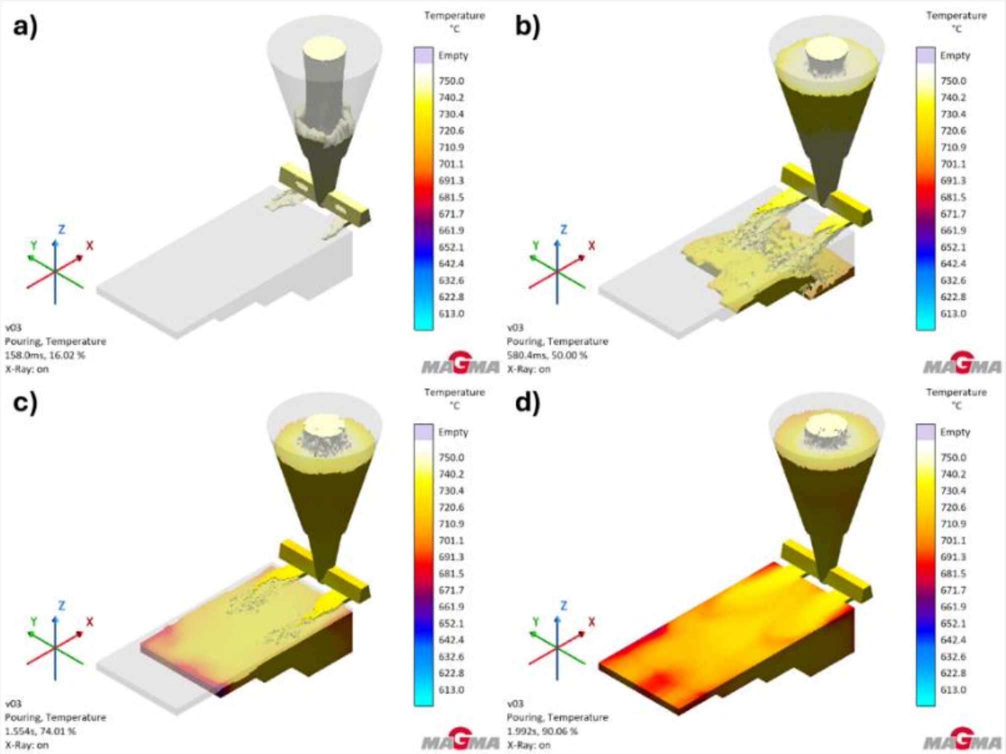

Figure 4. Temperature distribution in the test casting during the pouring process; a) at the moment of filling the gating system (18.00% of simulations); b) at the moment of pouring the casting (50.00% of simulations); c) at the moment of filling the last part of the casting (82.00% of the simulation); d) fully filled casting (89.94% of the simulation).

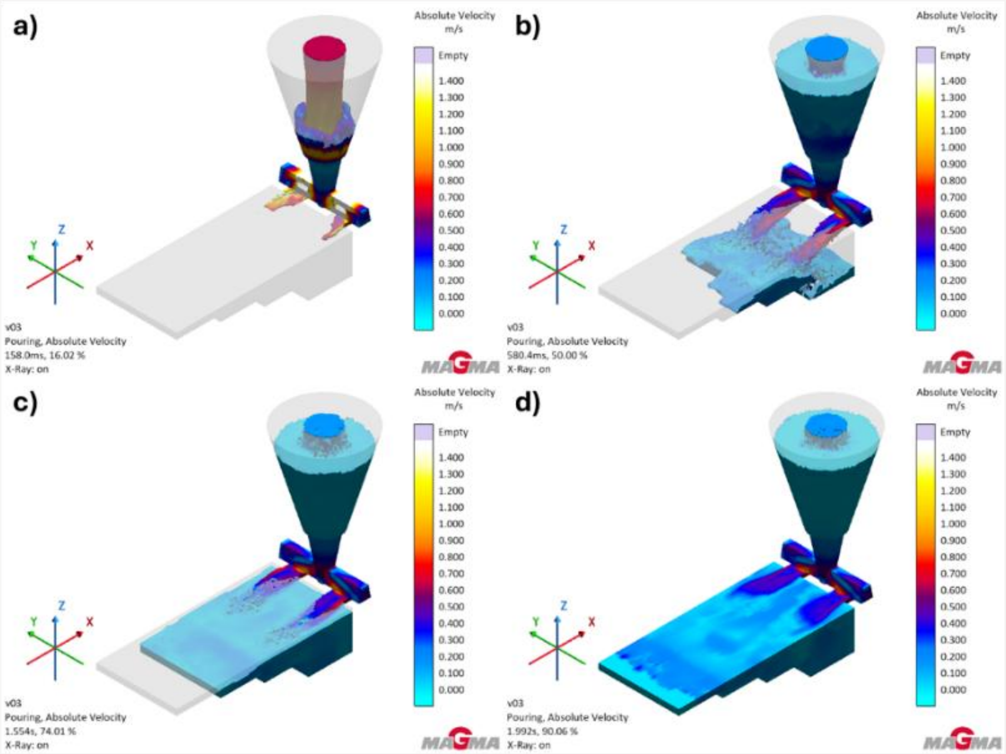

Figure 5. Velocity distribution in the test casting during the pouring process; a) at the moment of filling the gating system (18.02% of simulations); b) at the moment of pouring the casting (50.01% of simulations); c) at the moment of filling the last part of the casting (82.01% of the simulation); d) fully filled casting (89.94% of the simulation).

Simulation of casting, cooling and solidification process

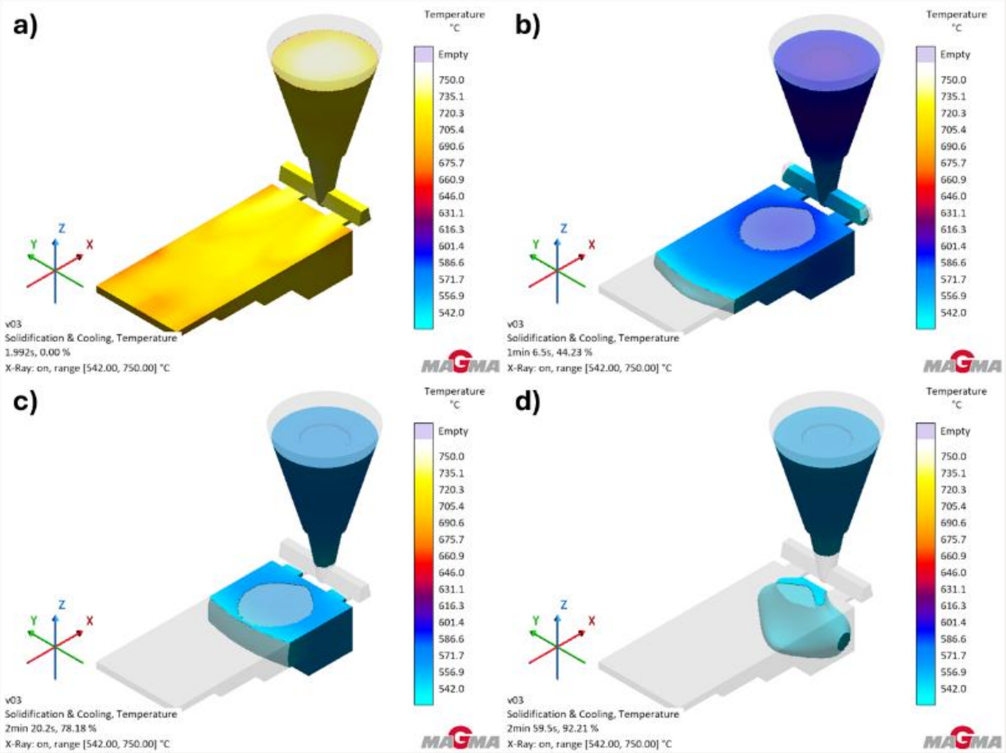

Figure 6. Temperature distribution during solidification and crystallization; a) at the end of the pouring process (0.00% of the simulation); b) at the moment of solidification of the first part of the casting (2.00% of the simulation); c) at the moment of solidification of ¾ of the casting (26.00% of the simulation); d) one step before the solidification of the last part of the casting (44.01% of the simulation).

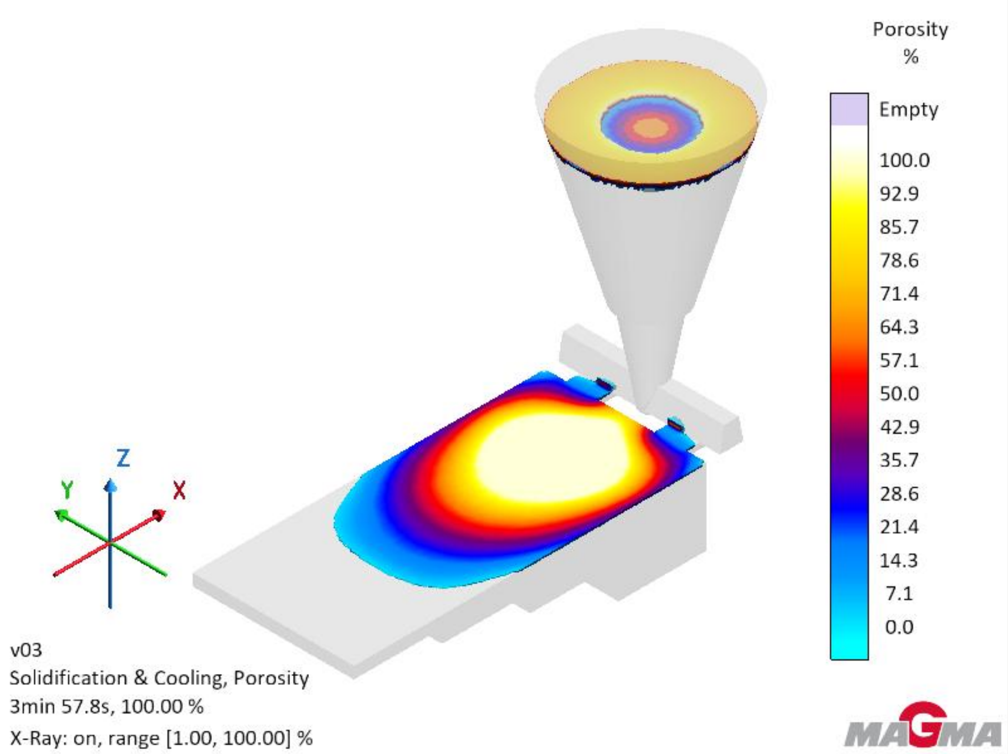

Figure 7. A place where porosity is likely to form during the solidification and crystallization process.

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Casting microstructure

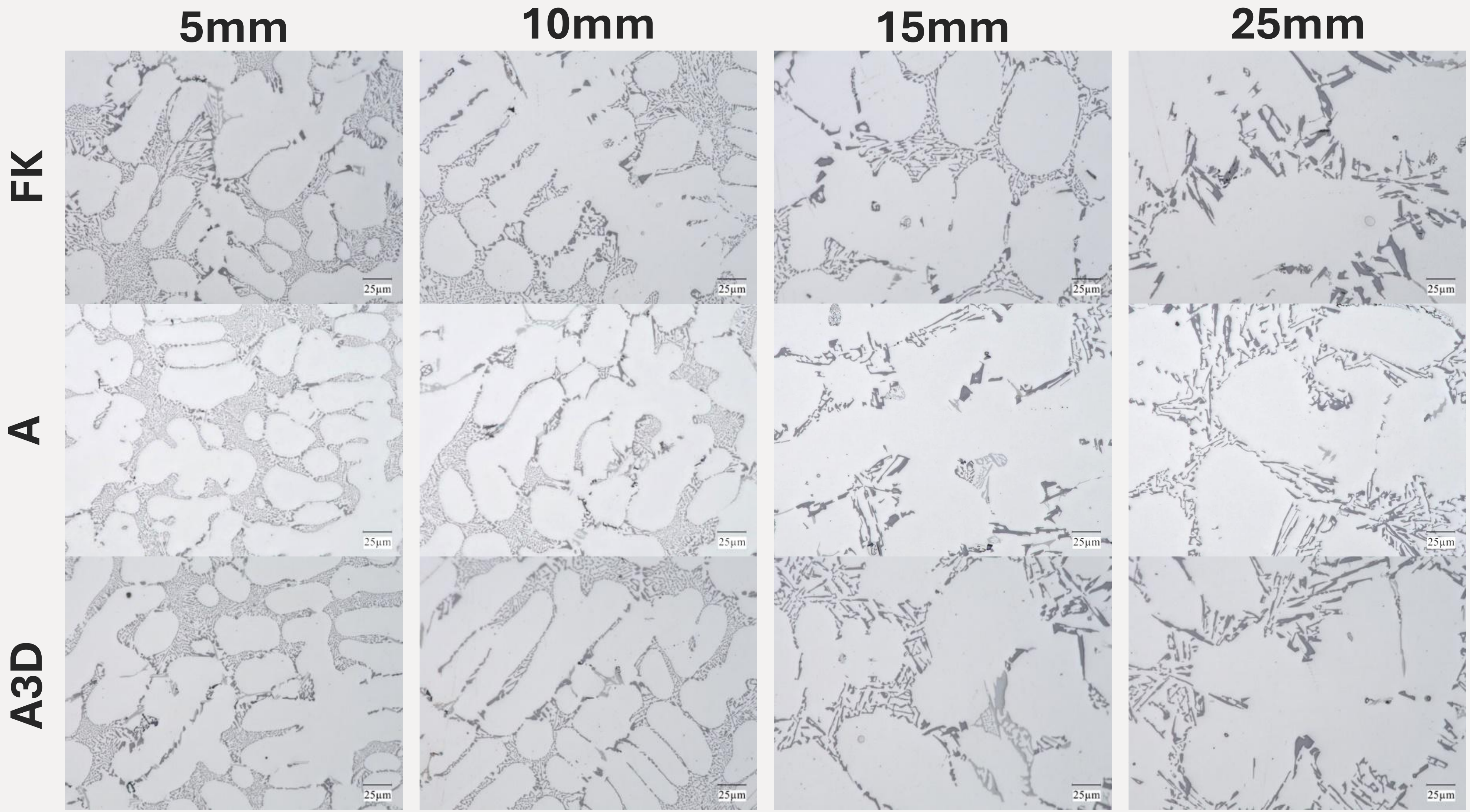

Figure 8. Microstructures of the tested AlSi alloy, depending on the binder used and the wall thickness of the casting.

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Casting microstructure

Table 3. Results of metallographic examinations.

Wall thickness, [mm]	Sample					
	A		A3D		FK	
	SDAS [μm]	Ef [%]	SDAS [μm]	Ef [%]	SDAS [μm]	Ef [%]
5	24.63	35.00	26.00	36.00	26.71	36.00
10	24.30	29.50	27.10	28.00	29.20	28.00
15	43.10	24.00	45.60	23.00	46.00	25.00
25	52.65	19.00	52.80	20.00	55.00	22.00

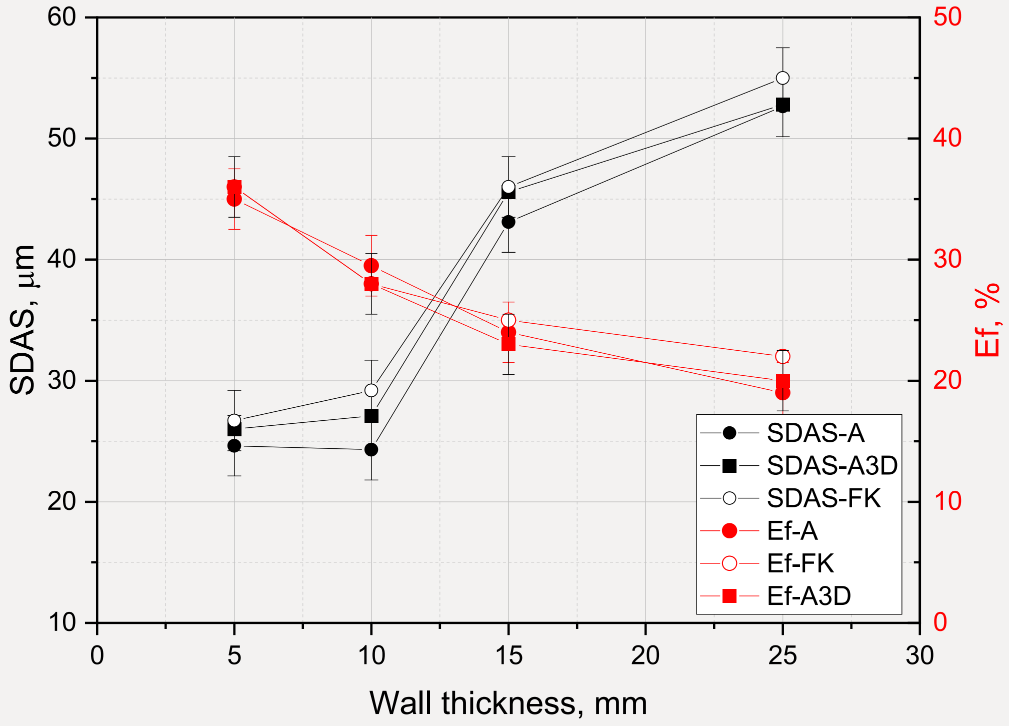

Figure 9. Secondary dendritic arm spacing (SDAS) and eutectic fraction (Ef) vs wall thickness.

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Roughness

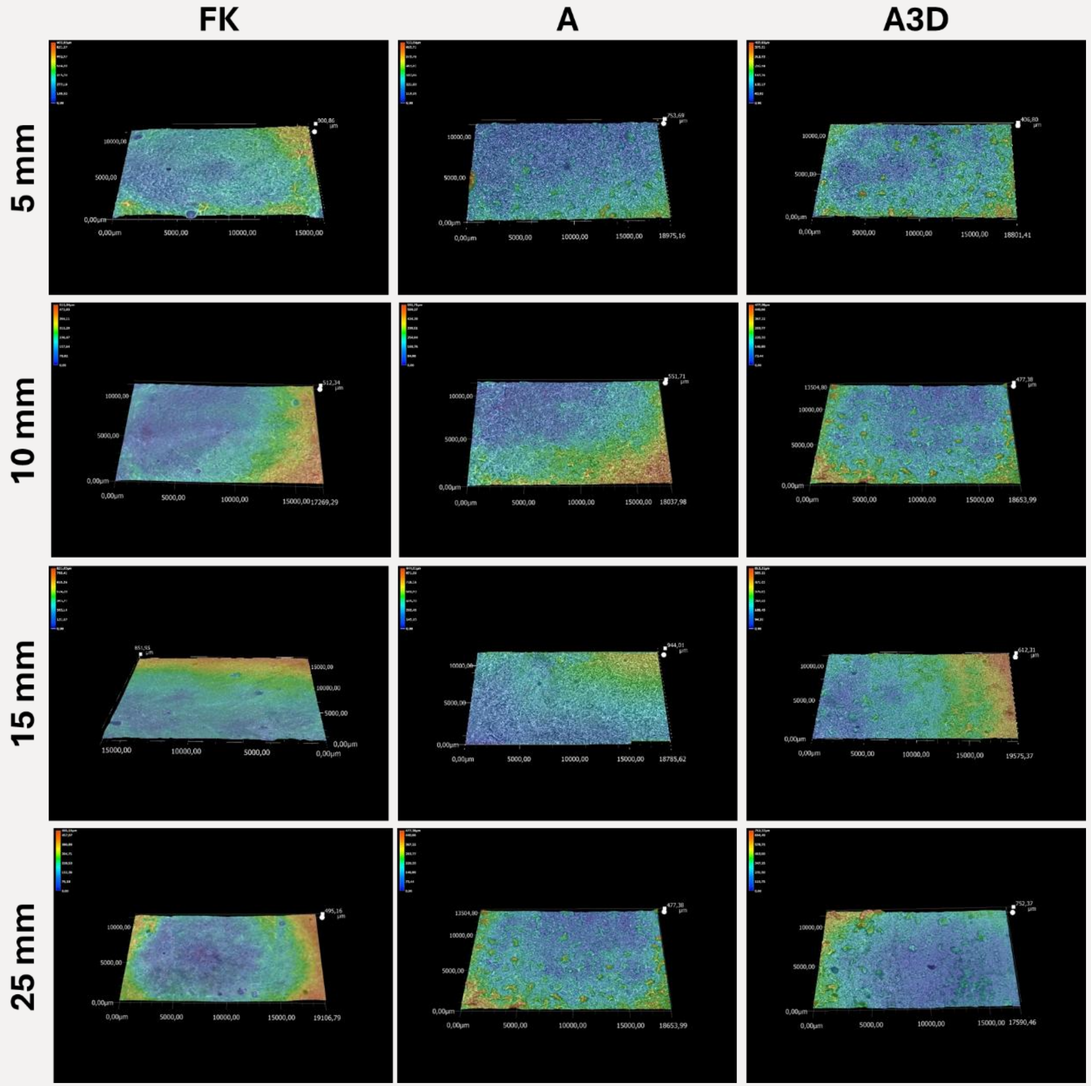

Figure 10. Roughness profiles of the tested castings depending on the type of binder used.

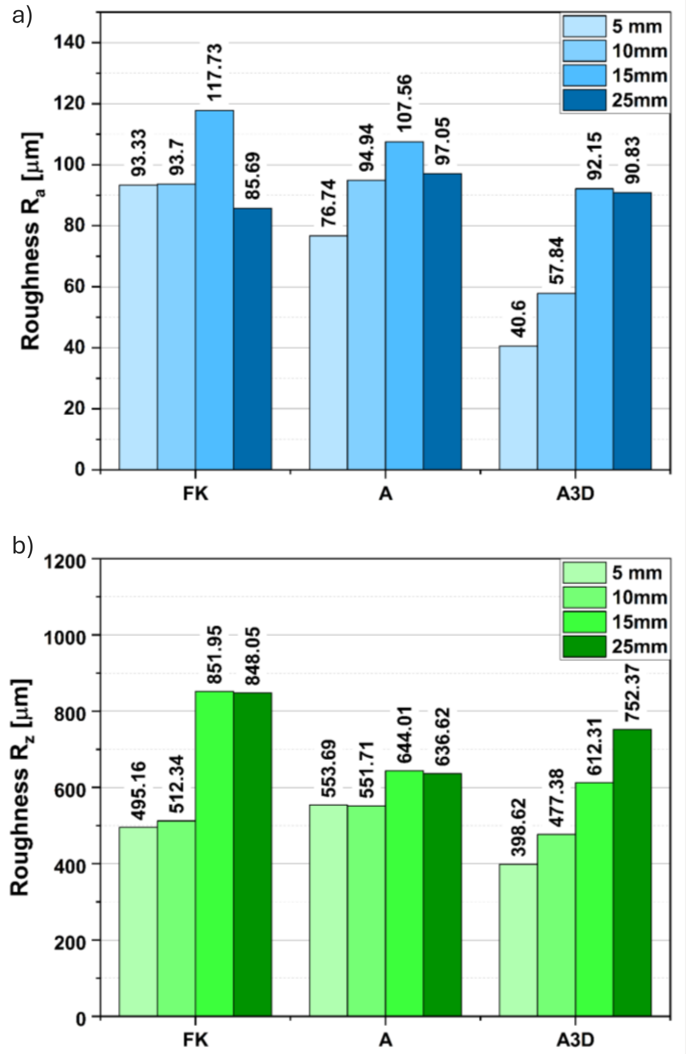

Figure 11. Summary of roughness results obtained from scanning: a) arithmetic mean deviation of the profile from the mean line (Ra); b) roughness height according to 10 points (Rz).

Microhardness

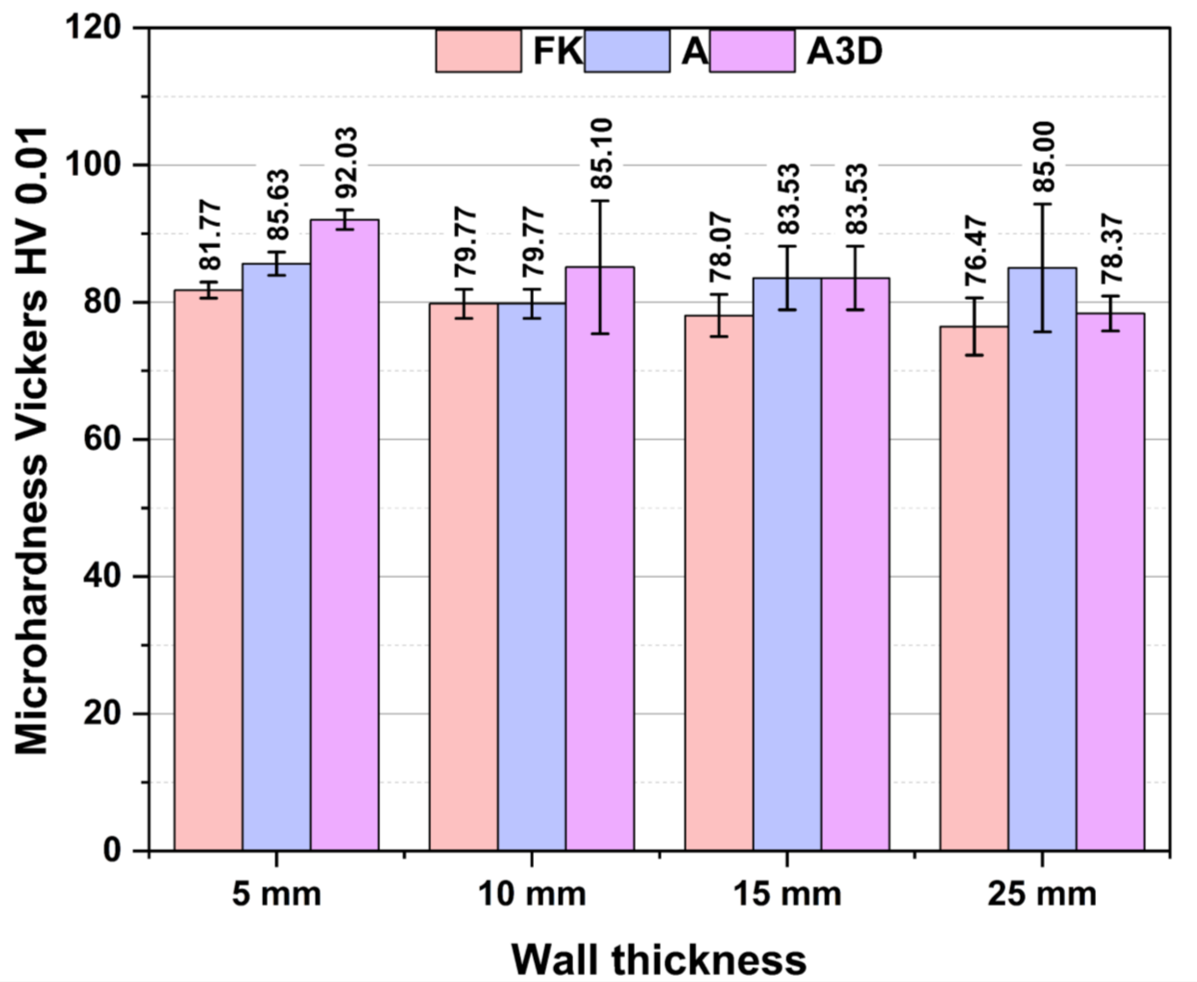

Figure 12. Microhardness results as a function of wall thickness and the binder used.

Conclusions

The conducted research effect of binder type (including inorganic binder designed for 3D printing) on the properties of the surface layer of castings made from aluminium alloys allow conclusions to be drawn :

- Numerical simulations confirmed the correctness of the design of the pouring system and the casting mold, allowing for uniform heating and smooth metal flow in the mold.
- The results indicate that the microstructure evolution is governed primarily by wall thickness–dependent cooling rate, whereas the influence of the moulding material on microstructural parameters is negligible.
- The type of binder used affects the surface quality of castings, as it was confirmed by surface topography images and roughness parameter results R_a and R_z.

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Thank you for your attention!

Acknowledgement
The research was co-financed within NetCastPL4.0 project. The project is funded by the European Union under the Horizon Europe programme, Grant Agreement No. 101159771.
The research was co-financed by AGH Research Project No 501.00 170000 10000 (16.16.170.654/B02).

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