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Original Article

PLA polymer binder in casting core production - influence on final casting dimensions

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Abstract: The foundry industry is seeking an ecological alternative to synthetic molding resins. This study evaluates the technological properties of core sands bonded with biodegradable polylactide (PLA). Cores prepared on a 2% quartz sand matrix were subjected to casting processes using two alloys with extremely different pouring temperatures: gray cast iron (approx. 1200 °C) and AK11 silumin (approx. 710 °C). The research methodology included macroscopic assessment, dimensional analysis using 3D scanning (GOM Inspect), and qualitative knock-out assessment supported by numerical temperature field simulation. The results showed that the high crystallization temperature of cast iron leads to complete thermal degradation of the binder, ensuring excellent knock-out properties.

Keywords: polylactide; foundry; sand cast molds; dimensioal accuracy of casting

Introduction

The modern foundry industry is characterized by ever-increasing quality requirements for manufacturing processes. Key criteria include not only low surface roughness and high dimensional and shape precision, but also strict repeatability of physicochemical properties and minimization of structural defects. In this context, the behavior of the casting core during the pouring process becomes a critical aspect of the process. This element, responsible for reproducing the internal geometry of the casting, is subjected to extreme thermal and mechanical loads, often exceeding those acting on the mold itself. Thermal interaction with the liquid metal initiates a number of phenomena, such as thermal expansion, thermoplastic softening, and thermal destruction of the binder material. The sum of these interactions determines the geometric stability of the system, directly impacting the quality of the final product [1].

To properly fulfill its function in such an aggressive environment, the core must exhibit a specific set of characteristics. High mechanical strength and fire resistance are key, ensuring dimensional stability. [1,2]. Equally important are technological properties such as high permeability and low gas formation (preventing gas defects) and susceptibility to shrinkage of the solidifying metal [3,4].

The production cycle is completed by the requirement of easy knock-out, resulting from the degradation of the binder after the process [5], while maintaining high dimensional precision and moisture resistance at the storage stage [6–8].

The core mass is a heterogeneous system in which the granular matrix (usually quartz sand) is stabilized by a binding agent. The physicochemical properties of the binder primarily determine the final technological parameters of the core [8]. Contemporary ecological conditions require the search for binding materials with minimal environmental impact.

In this context, polylactide (PLA) appears to be a promising biodegradable alternative [9], but its impact on dimensional stability and precision of core shape mapping requires in-depth verification. Despite the extensive literature on general industrial applications of PLA and methods for modifying its mechanical properties [10–13], implementation [14,15] of this polymer in foundry technologies remains limited. The potential of PLA as a binder stems from its favorable rheological properties and adhesion to the matrix grains. Research indicates that core sands based on PLA composites exhibit technological properties comparable to traditional sands bonded with synthetic resins. [16–18].

Materials and Methods

Input materials

Medium-grained quartz sand, supplied by the RETRANS Mining and Underwater Works Company, was used as the core sand matrix. Lactide (produced by Sigma-Aldrich) was used as the binder. The casting molds were made of classic synthetic molding sand with a bentonite binder (approximately 10% by weight) and an operating moisture content of approximately 3%.

Preparation of cores and molds

The core sand composition consisted of 98% by weight of a quartz matrix and 2% by weight of a polylactide (PLA) binder. The binder was introduced into the matrix through the physicochemical process of PLA deposition on the surface of sand grains, according to the methodology described in the literature. [16,17]. The cross-linking (curing) process of the molds was carried out in a resistance furnace without a protective atmosphere. The samples were heated at 230°C for 20 minutes. The temperature control system ensured process stability with an accuracy of ±3°C. After thermal treatment, the cores were cooled at ambient conditions for 30 minutes and then disassembled from the core boxes. Four sets of molds with identical molding parameters were prepared. The casting models were manufactured using FDM (Fused Deposition Modeling) additive technology using a MakerBot Replicator 2X 3D printer.

Experiment plan and casting process

A test casting was designed with the geometry shown in **Fig. 1**. The model dimensions were selected to ensure a core heat storage coefficient of 0.5, which was intended to simulate the conditions of slow core overheating. Two casting materials with different solidification temperatures were selected for testing:

- grey cast iron (pouring temperature T_P≈1200 °C),
- silumin AK11 (pouring temperature T_P≈710 °C).

Two forms were prepared for each alloy, introducing the core surface condition as a variable:

- reference core: without protective coating,
- research core: with graphite coating (aerosol preparation dedicated to foundry applications).

The coating was applied to the cylindrical surface of the core, which was the zone of direct contact with the liquid metal. After assembling the mold packages and transporting them to the casting station, the cavities were filled with liquid metal. The process temperature was monitored in real time using an immersion thermocouple. After the castings had completely solidified and cooled, the knockout process began. Initial macroscopic assessment and surface analysis of the castings were performed immediately after disassembly of the upper molding box.

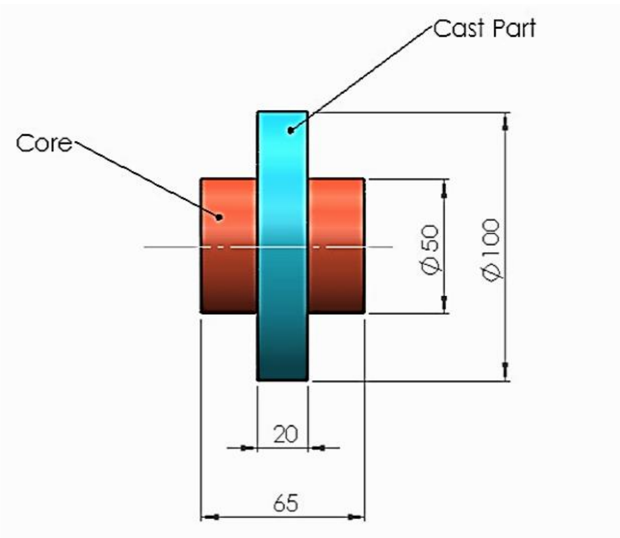


Fig. 1. Casting and core geometry

Geometric measurement methodology

Due to the specific surface characteristics of raw castings, which are characterized by significant roughness, conventional measurement methods (calipers, internal diameter gauges) were abandoned, as they would have been subject to significant measurement error. Reverse engineering and optical metrology techniques were used for dimensional verification [19]. The measurement process was carried out in two stages. The geometric shape of the castings was mapped using a 3D scanner, resulting in a point cloud converted to STL format. Based on the imported digital models, a virtual inspection was performed in GOM Inspect software. Approximation algorithms were used to determine the actual hole diameter, incorporating the best-fit cylinders into the internal geometry of the casting. This allowed for averaging surface irregularities and obtaining reliable measurement results. (**Fig. 2**).

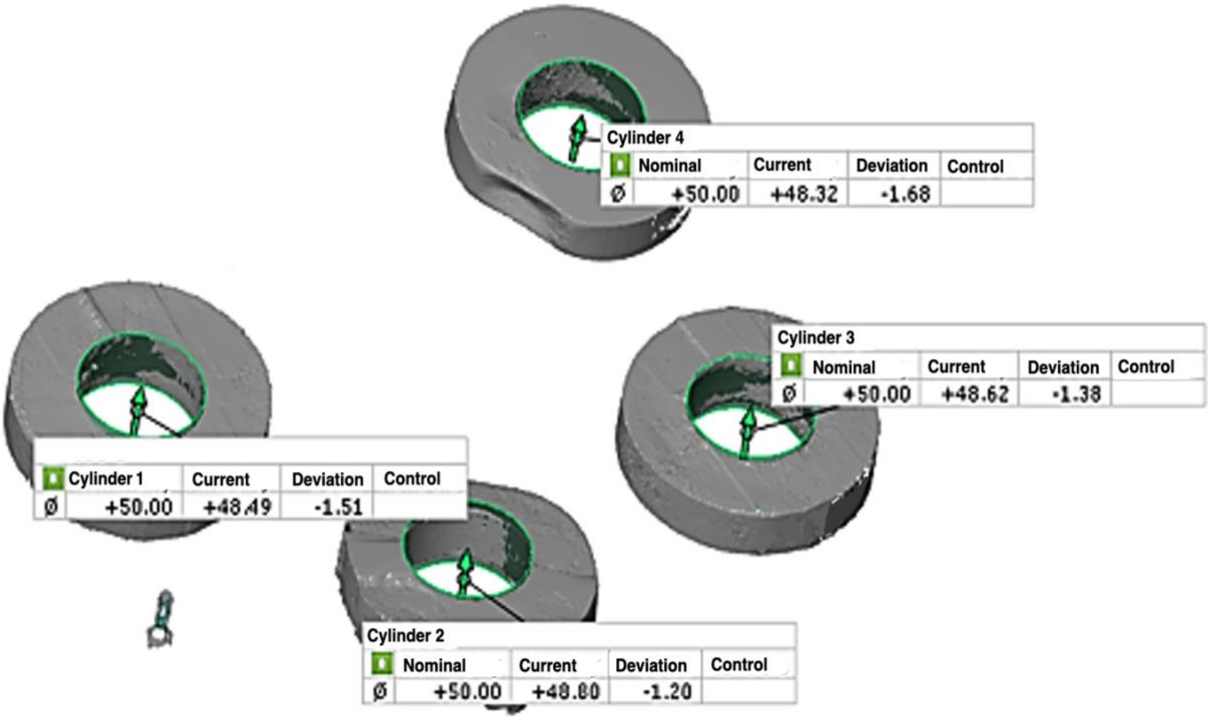


Fig. 2. Hole measurements using the GOM Inspect tool

Results

Macroscopic analysis and surface quality assessment

The initial assessment of the casting quality was based on macroscopic observations, with particular emphasis on the fidelity of the core geometry (cylindrical bore ϕ50). For both materials tested – gray cast iron and silumin – the geometric shape of the bore was accurately reproduced. Comparative analysis revealed varying effects of the protective coating on the casting surface topography depending on the alloy used:

- Iron castings: No significant effect of the presence of graphite coating on the quality of the internal surface of the casting was found.
- Aluminum castings: A clear difference in surface structure was observed. The use of a graphite coating resulted in a significant reduction in surface roughness. In the case of uncoated (reference) cores, the internal surface of the casting was characterized by irregularities, indicating the presence of surface defects such as penetration (mechanical penetration of liquid metal into the pores of the core mass). The surface reproduced by the graphite-coated core exhibited higher smoothness and shape regularity.

Evaluation of core knockout properties

The key technological parameter assessed was knockout properties, defined as the ability of the casting mass to decohes under the influence of a thermal factor. The assessment was conducted qualitatively after the castings had completely cooled. Fundamental differences in the behavior of the PLA binder were observed depending on the melt pouring temperature:

- Gray cast iron (T_p≈1200 °C): High solidification enthalpy and process temperature led to complete thermal degradation of the PLA binder bridges. Complete disintegration of the core sand was observed – the sand regained its flowability, without any agglomerates (solidified lumps of sand). This indicates excellent knock-out properties, regardless of the presence of a protective coating.
- Silumin AK11 (Tp≈710 °C): Due to the lower pouring temperature, the binder degradation process was less intense. Decohesion of the mass occurred only in the zone of direct contact with the metal (the near-surface layer). The core retained its volumetric integrity, necessitating the use of mechanical energy to remove it from the casting. Despite partial degradation, the internal geometry was preserved.

Dimensional accuracy analysis

The research focused on analyzing the characteristic dimension represented by the core – a diameter of ϕ50 mm. The obtained results were referenced to the ISO 8062:1997 standard, which governs the system of dimensional tolerances and machining allowances for castings. For sand molding technology, the CT12 tolerance class was adopted [20].

According to the standard, for a nominal dimension within the range of 50 mm, the total tolerance is 5.6 mm. Assuming a symmetrical tolerance zone, the permissible limit values are: maximum dimension: Ø52.8 mm; minimum dimension: Ø47.2 mm.

The measurement results are summarized in **Tab. I.** Data analysis indicates that all obtained dimensions fall within the permissible tolerance range CT12. It should be noted that all recorded deviations are negative. This phenomenon is justified by the occurrence of casting shrinkage, which for the tested materials is:

- Silumin AK11 (eutectic alloy): linear shrinkage approximately 1,1% – 1,2%,
- Gray cast iron: linear shrinkage approximately 0,8% – 1,2%.

Negative dimensional deviations of holes (reduction in diameter) are a natural consequence of the free contraction of the solidifying metal on the core, while the observed partial flexibility of the cores (especially in the case of cast iron) did not completely block this process.

Table I Casting hole dimensions. Index 1 is uncoated, index 2 is coated

Gray cast iron 1	Gray cast iron 2	Aluminum 1	Aluminum 2
Ø 48,90	Ø 48,49	Ø 48,32	Ø 48,80

In order to explain the fundamental differences in the knockout process of cores from iron and aluminum castings, a comparative analysis of the temperature distribution inside the core at the solidification stage was performed (**Fig. 3**). Comparison of the simulation results with the physicochemical characteristics of the PLA binder (glass transition temperature T_g≈60 °C, onset of degradation T_{onset}≈200 °C, specific degradation 300-380 °C) allows for the definition of thermal impact zones.

The near-surface zone (metal-core contact surface) occurs in the area of direct contact with the liquid metal (Callout 6), for both materials the temperatures recorded exceeding the thermal degradation threshold of polylactide:

- Gray cast iron: 387,33 °C (maximum decomposition rate),
- Silumin AK11: 330,81 °C (extent of degradation).

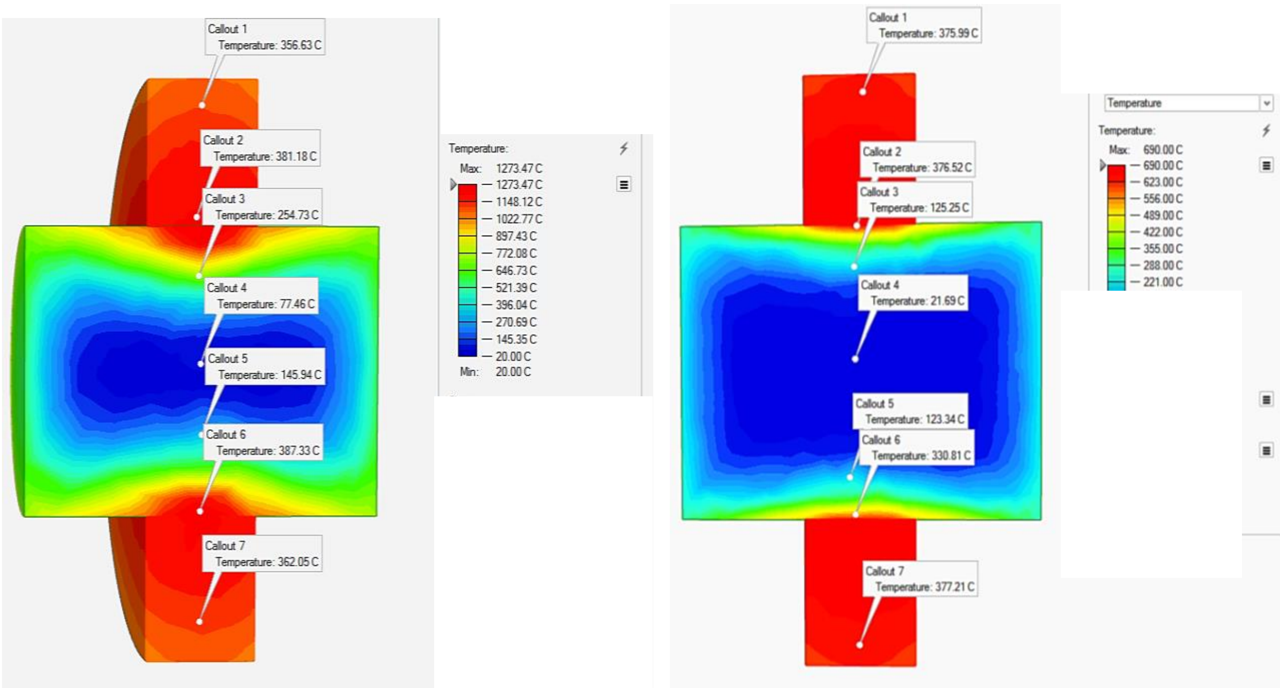
In both cases, rapid pyrolysis of ester bonds occurs in the thin boundary layer. This explains the good internal surface quality and lack of defects in both iron and aluminum castings – the binder undergoes complete gasification there. In the intermediate zone, heat propagates into the core, which is a key difference determining knockout properties. This difference manifests itself in the deeper core layers (Callout 3), resulting from the drastically different enthalpy of the system (pouring temperature 1200 °C for cast iron vs. 710 °C for aluminum):

- Gray cast iron (**Rys. 3a**): The temperature at the intermediate point (Callout 3) reaches 254.73 °C. This value exceeds the Tonset temperature (200 °C). This means that the thermal degradation front of the binder has moved deep into the core structure. Polymer bonds are broken not only on the surface but also throughout a significant volume of the mass.

- Silumin AK11 (**Rys. 3b**): At the same point (Callout 3), the temperature is just 125.25 °C. This is above the glass transition temperature but well below the chemical degradation temperature. In this zone, the PLA binder only softens (plasticizes) but does not decohes. After cooling, the material hardens again, maintaining the mechanical cohesion of the core.

The analysis of the temperature in the core axis (Callout 4) confirms the different heating dynamics:

- in the cast iron reaches a temperature of 77.46 °C. The entire core volume has exceeded the glass transition temperature (T_g≈60 °C), which means that the entire core has entered a highly elastic state, and the supplied thermal energy promotes further degradation during cooling,
- the center of the aluminum casting core remains cool (21.69 °C), which indicates that the core has retained its "glassy" and intact structure in its axis.



(a) (b)

Fig. 3. Simulation results of temperature distribution during solidification of castings with a PLA binder core: a) cast iron, b) aluminum

Conclusions

The experimental studies and numerical simulations conducted allowed for a comprehensive assessment of the suitability of polylactide (PLA)-binder core sands for casting iron and aluminum alloys. Analysis of the effect of pouring temperature on binder degradation, surface quality, and dimensional accuracy allows for the following conclusions:

- The knockout properties of PLA-bound cores are closely correlated with the metal's solidification enthalpy. In the case of gray cast iron (T_P≈1200 °C), high process temperatures initiate complete thermal degradation of the polymer matrix (pyrolysis) throughout the core, resulting in excellent knockout properties (spontaneous sand shedding). In the case of silumins (T_P≈710 °C), the heat input is insufficient to exceed the PLA degradation temperature (>200 °C) at the core axis. This leads to the preservation of the mechanical integrity of the central core zone, which complicates the knockout process and requires the use of mechanical methods.
- Computer simulations confirmed the experimental knock-out mechanism. Analysis of temperature fields showed that in aluminum-poured cores, the binder degradation zone (temperature >300°C) is limited to a thin surface layer. The core interior reaches temperatures of around 125°C (intermediate zone) or remains close to ambient temperature (core), resulting

only in reversible binder plasticization, not permanent destruction. For cast iron, the degradation isotherm penetrates the core almost throughout its entire volume.

- The effect of a graphite coating on surface quality depends on the type of casting material. For aluminum alloys, the use of a coating is crucial to eliminate penetration defects (metal penetration into the pores of the casting mass) and reduce roughness. In the case of gray cast iron, due to the rapid gasification of the binder at the contact point with the metal, satisfactory surface quality was achieved for both coated and uncoated cores.
- The PLA technology used allows for the production of castings with high dimensional accuracy. All measured geometric characteristics (⌀50 hole) fall within the CT12 tolerance class according to the PN-ISO 8062:1997 standard. The recorded negative dimensional deviations are the result of natural casting shrinkage (of the order of 1.1–1.2% for AK11 and 0.8–1.2% for cast iron), which indicates that the core, despite its strength, exhibits a certain flexibility, not completely blocking the shrinkage of the solidifying metal.
- PLA-binder molding sands show great potential as an ecological alternative in the casting of high-melting-point alloys (cast iron), guaranteeing excellent knockout properties. In the case of light alloys (Al, Mg), this technology requires optimization – for example, modifying the core geometry (thin-walled cores) or modifying the binder composition to lower its degradation temperature to avoid problems with sand removal from the interior of the casting.

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References

1. Lewandowski, J.L. *Tworzywa na formy i rdzenie*; Wydawnictwo Naukowe PWN: Warszawa, 1991;
2. Beeley, P.R. *Foundry Technology*; 2nd ed.; Butterworth-Heinemann: Oxford, 2001;
3. Sakwa, W.; Wachelko, T. *Teoria i praktyka materiałów formierskich*; Wydawnictwo Śląsk: Katowice, 1981;
4. Campbell, J. *Complete Casting Handbook: Metal Casting Processes, Metallurgy, Techniques and Design*; Butterworth-Heinemann: Oxford, 2011;
5. Holtzer, M.; Dańko, R.; Żymankowska-Kumon, S. *Materiały wiążące stosowane w masach formierskich i rdzeniowych – wybrane zagadnienia*; Wydawnictwo Naukowe AKAPIT: Kraków, 2014;
6. Tabor, A.; Rączka, J.S. *Odlewnictwo*; Wydawnictwo-Dydaktyczne AGH: Kraków, 1996;
7. Jain, P.L. *Principles of Foundry Technology*; 5th ed.; Tata McGraw-Hill Education: New Delhi, 2009;
8. Ettemeyer, F.; Lechner, P.; Hofmann, T.; Andrä, H.; Schneider, M.; Grund, D.; Volk, W.; Günther, D. Digital sand core physics: Predicting physical properties of sand cores by simulations on digital microstructures. *Int. J. Solids Struct.* **2020**, *188–189*, 155–168, doi:10.1016/j.ijsolstr.2019.09.014.
9. Nowak, B.; Pająk, J. *Biodegradacja polilaktydu (PLA)*; Katedra Biochemii Wydział Biologii i Ochrony Środowiska Uniwersytet Śląski, 2010;
10. Fabijański, M.; Garbarski, J.; Szymaniak, Z. Modifying Polylactide with Powdered Cork Filler. *Materials (Basel).* **2025**, *18*, 5606, doi:10.3390/ma18245606.
11. Fabijański, M.; Gołofit, T. Influence of Processing Parameters on Mechanical Properties and Degree of Crystallization of Polylactide. *Materials (Basel).* **2024**, *17*, 3584, doi:10.3390/ma17143584.
12. Tyler, B.; Gullotti, D.; Mangraviti, A.; Utsuki, T.; Brem, H. Polylactic acid (PLA) controlled delivery carriers for biomedical applications. *Adv. Drug Deliv. Rev.* **2016**, *107*, 163–175, doi:10.1016/j.addr.2016.06.018.
13. Farah, S.; Anderson, D.G.; Langer, R. Physical and mechanical properties of PLA, and their functions in widespread applications — A comprehensive review. *Adv. Drug Deliv. Rev.* **2016**, *107*, 367–392, doi:10.1016/j.addr.2016.06.012.
14. Garlotta, D. A literature review of poly(lactic acid). *J. Polym. Environ.* **2001**, *9*, 63–84, doi:10.1023/a:1020200822435.
15. Auras, R.; Lim, L.T.; Selke, S.E.M.; Tsuji, H. *POLY(LACTIC ACID): Synthesis, Structures, Properties, Processing, and Applications*; John Wiley & Sons, Inc., 2010; ISBN 9780470649848.
16. Tryznowski, M.; Soroczyński, A. Use of biodegradable poly(lactic acid) as a binder for molding sands for foundry industry. *Przem. Chem.* **2020**, *2020*, 146–149, doi:10.15199/62.2020.10.23.
17. Kozłowski, J.; Kochański, A.; Perzyk, M.; Tryznowski, M. Zastosowanie PLA jako spoiwa w masach formierskich i rdzeniowych. *Arch. Foundry Eng.* **2014**, *14*, 51–54.

18. Upadhyay, M.; Sivarupan, T.; El Mansori, M. 3D printing for rapid sand casting—A review. *J. Manuf. Process.* **2017**, *29*, 211–220, doi:10.1016/j.jmapro.2017.07.017.
19. Gołaszewski, M.; Grygoruk, R.; Bissenik, I. 3D printing and 3D scanning processes applied to design and to produce artificial limb for animal. *Mechanik* **2015**, 682–684, doi:10.17814/mechanik.2015.8-9.498.
20. Geometrical product specifications (GPS) - Dimensional and geometrical tolerances for moulded parts - Part 1: Vocabulary (ISO 8062-1:2007) 2008.