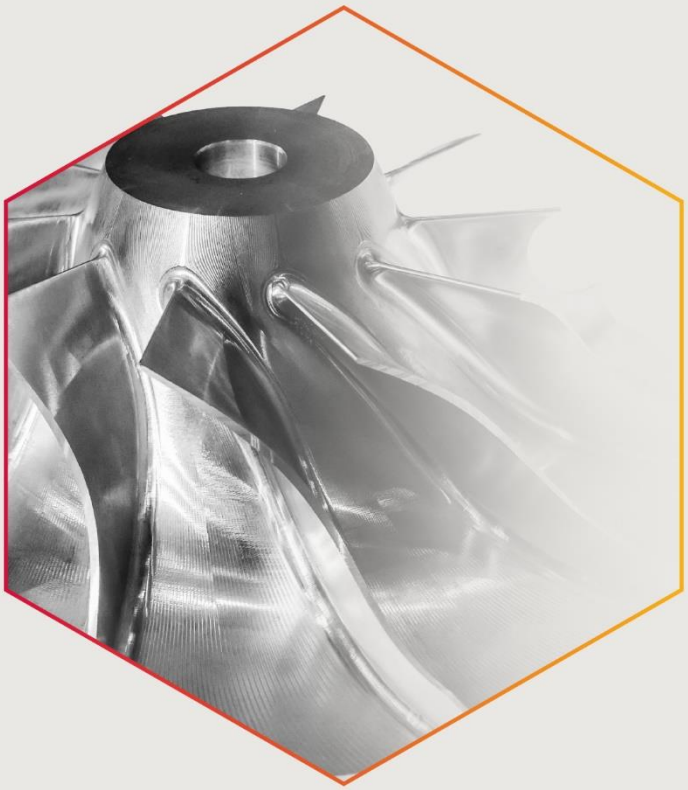
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D4.2. Roadmap on Exploitable Light-Weight Castings

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PU	**Public**	☑
SEN	**Sensitive**	☐

NetCastPL4.0 aims to enhance excellence and innovation capacity at AGH, putting AGH in a leading position to nuclei the Networking Pole for Castings Foundry Innovation and Sustainability to face the strategic challenges of Poland and EU foundries and of lightweight components end-user industry. It also aims to engage the country in pan-European collaborative efforts on this topic twinning with the Consiglio Nazionale delle Ricerche (Italy) and AALTO University (Finland). It will put AGH This will be achieved through realization of following specific objectives implemented via 7 WPs:

1. Improving the overall capacity and resources at AGH in advanced lightweight castings science & technology and in emerging Industrial Sustainability assessment and management practices and tools.

2. Conducting exploratory research on “High-tech cast iron and Al alloys for lightweighting castings for the medium and heavy-loaded conditions produced by green molding materials” demonstrating enhanced capacity in novel lightweight materials and components fabrication, modelling and characterization.

3. Establishing an AGH European Networking Pole on Lightweight Castings Innovation and Sustainability. This will enhance the replication potential developed at AGH, creating strategic partnerships with Research organizations, Universities, Foundries, Industry, Public and Governmental Organizations, and Agencies in light-weighting casting components and Technologies for casting foundries 4.0 development.

4. Providing new results and experiences analyzing 3 case-studies in production of light-weight castings components in medium and heavy loaded conditions and automotive for the preparation of a Guide Document on Best Available Practices in the Green Foundries Industry.

5. Leveraging the NetCastPL4.0 partnership at a European level and creating the enabling conditions for a long-lasting joint collaboration.

6. To arrange schools and training workshops in partner countries for scientists and for potential follower foundries and other relevant stakeholders.

7. Raising mobility (internal and external) of scientists and staff in green molding/casting science and technologies.

8. Improving the research management and administration skills at AGH, by creating the Department of European cooperation within AGH.

9. Fostering gender equality issues at AGH and in the castings foundry through implementation of the action plan for Equality, Inclusion, and Diversity.

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1. Scope of the Deliverable

As a cornerstone of modern manufacturing, metal casting involves pouring molten metal into either expendable or permanent moulds to create specific geometries. This process is essential for realizing large and complex components used across the automotive, construction, metallurgical, and medical sectors. Currently, the light metal casting market is seeing significant growth. Indeed, as the target is the weight reduction of transportation vehicles and the industry components in general driven by increasingly stringent European environmental regulations and energy efficiency standards, the overall strategy for complying to those targets is the light-weight design, where, of course, the increase of light metals use is obviously the prime approach. However, lightweight design means a wider approach that aims to putting the mass only where it is needed, i.e., the load is applied, and nature can be inspiring in the approach called bionic design. Foundry manufactures and in particular thin-walled castings represent one of the strategic technologies to achieve this target.

The lightweight castings that have been identified as potentially usable in the previous report *D4.1 Roadmap on Green technologies for lightweight castings*, are made of aluminum alloys for non-ferrous alloys (while magnesium alloys represent a little share of the Polish market), and conventional and advanced cast irons, while cast steels are not because of the difficulty of production, and nickel-base superalloys are well-established, but have little share of the Polish market because of the high technology request for production and valuable but little market for aerospace and energy. Consistently, the NetCastPL4.0 project is focused on the research, development and exploitation of thin-walled castings of high strength Al-Cu alloys and also Austempered Ductile Irons (ADIs) and Si-Mo ductile irons that, thanks to the density between 10 and 12% lower than steels, can achieve high specific strength to be potential candidates to substitute steels in some heavy transportation and industrial applications. The present report *D4.2 Roadmap on Exploitable Lightweight Castings* is focused on analyzing the possible gaps between the lab-scale prototypes of the innovative lightweight castings produced in academia and research centers (i.e., NetCastPL4.0 project) and the industrial production, with the intention of bridging them to aim at their industrial exploitation in the future.

The compiled data in this report consists of the following:

- Analysis on the current states of the thin-walled castings production in Poland.
- Analysis of future targets in the thin-walled castings production.
- Analysis of the actions needed to bridge the gaps between current state and future targets in foundries to produce thin-walled castings.

2. Networking for Light-Weight Castings

2.1. Background

The NetCastPL4.0 project focuses on researching high-tech alloys to facilitate the lightweighting of castings using Al-Cu alloys and innovative cast irons, by means of sustainable and green moulding materials. Building on previous European research and international partnerships, the project aims to foster economic growth while prioritizing environmental conservation. Complying with European CO_2 reduction regulations, there is an increasing industrial demand for materials with superior strength-to-weight ratios and innovative design. Consequently, future R&D must adopt an integrated approach that simultaneously balances market requirements, material performance, light-weight design and ecological sustainability. The work on this topic is based on interactions via surveys with the foundries and the stakeholders involved in the Networking of NetCastPL4.0 project that have shared a stimulating discussion on how the production of the thin-walled castings **IS** now in Poland; the prediction of how it **WILL BE** in 2030; and the gaps that have to be bridged from now to 2030.

2.2. Previous Work in NetCastPL4.0

During the NetCastPL4.0 projects, surveys have been already commissioned to foundries and stakeholders to gather information about the state of the market in Poland and, in particular, on light-weight components production and their capabilities and needs to produce thin-walled castings. The results of these surveys have been already analysed in NetCastPL4.0 Work Package 6, the *D4.1. Roadmap on Green technologies for lightweight castings* has been produced. In it, the needs for the Polish foundries in terms of thin-walled castings were identified based on interview to the Polish Foundry Chamber of Commerce (*Report - Production of thin-walled castings in Poland compared to Europe, including casting alloys: superalloys, aluminium alloys, ductile cast iron, and cast steel. Current status and perspectives*), and the interview to the Polish Foundrymen's Association (*Market and Market Needs Analysis in the Area of Lightweight Castings for Foundry 4.0 in Poland*).

The reports are available through the NetCastPL4.0 E-Library.

During the NetCastPL4.0 network partners meeting in AGH, Faculty of Foundry Engineering, on 20 February 2026, other two surveys were delivered to the meeting attendees:

- *Survey Nr. 1: Roadmap for Thin-walled Castings Production*, that was focused on gathering information about what is the present production of thin-walled castings in Poland; what the production will be in 2030; what are the gaps of thin-walled production between now and 2030; and suggestions on which actions will be expected to take to bridge these gaps.
- *Survey Nr. 2: Research and Professional Career Enhancement*, that was focused on the attractiveness of the foundry economical sector for the young generations of engineers and technical personnel, looking with particular attention at the gender issue.

The information from the previous work reported in *D4.1. Roadmap on Green technologies for lightweight castings* and the results from both the two surveys were used to write the present report *D4.2 Roadmap on Exploitable Lightweight Castings.*

2.3. Surveys Respondents

The surveys (Annex) respondents were mainly from industry and foundry, representing a quite valuable statistics for the aim of the present assessment on how the present production of thin-walled castings is in Poland now, and on how the production will be in 2030, gathering suggestions on the gaps that are to be filled to bridge those gaps. Indeed, the repliers of the surveys come for 41% from foundries, 22% from software suppliers, while only 19% are from Universities and Research Centres. From the industrial side, 32% belongs to large companies while 39% come from SME.

It is interesting to underline that 84% of the attendees are interested in research projects, 58% in hosting students and (Masters and PhD projects), which indicate that the network partners from the industries are strongly interested in innovation and development. In fact, the people involved in the survey are involved in automotive sector at some stage of production (89% of the respondents), where the European regulations are particularly demanding for reducing weight and CO_2 and pollutant emissions: their interest in light materials and light-weight design and thin-walled castings is paramount. For the rest, between 50 and 60% are involved in energy production, heavy machinery, railway and defence. All of these sectors are particularly needing for innovation and development.

About the materials production, the partners are mainly involved in making thin-walled castings (≤ 3mm) of cast irons, and aluminium alloys and nickel-based superalloys for non-ferrous alloys, which is consistent with the actual foundry production in Poland reported in *D4.1. Roadmap on Green technologies for light-weight castings*.

3. Present Production of Light-Weight Castings

Currently, the most pressing challenge facing the foundry industry is the rising demand for secondary metallurgy. This concern is primarily driven by the circular economy mandates established by the European Commission, which prioritize resource efficiency and waste reduction. Beyond regulatory requirements, there is also significant social and commercial pressure; end-users increasingly demand certifications for recycled material content as a core component of their marketing and sustainability strategies.

The environmental and economic incentives for this transition are clear, and Industry data confirm this trend: approximately 52% of manufacturers of the NetCastPL4.0 networking now use secondary alloys extensively in their production cycles, with another 28% utilizing them partially at some stage of manufacture. Only a small minority of the respondents (20%) claim to avoid secondary alloys entirely.

However, the transition to recycled materials is not without technical hurdles. The respondents report significant challenges regarding melt contamination (81%) and compositional instability (62%). If not managed precisely, these factors can lead to detrimental effects on the microstructure and mechanical properties of the final castings, which represent risks that cannot be underestimated in high-performance applications. Furthermore, the recovery of Critical Raw Materials (CRMs), cited by 38% of industry experts, has become a vital geopolitical priority. Ensuring a stable supply of these materials is essential for technological sovereignty and industrial stability.

Consequently, the hiring strategy in the foundries is evolving rapidly. Companies are actively seeking for experts in advanced simulation software (e.g., ProCAST and MAGMASOFT), as well as specialists in Artificial Intelligence (AI) and Machine Learning. These former technologies are envisaged for enhanced quality control (42%) and innovative alloy design (32%) because of challenging secondary metallurgy, but also traditional high quality and low scrap-rate conventional production. Additionally, Life Cycle Assessment (LCA) expertise is in high demand (32%), reflecting the industry's need to quantify its environmental impact accurately. This direction is further validated by educational trends suggested by the respondents to the young engineers, advising students to specialize in recycling and CRM recovery (71%), additive manufacturing (55%), and the development of digital twins powered by AI.

According to the survey results, thin-walled casting production is not the present issue, and represents a major and ongoing challenge for the foundry industry. Far from being settled, thin-walled casting production is currently seen as one of the most strategic areas of future development, particularly due to the lightweighting trend. Indeed, simulations seem to be a trustable tool in this issue, like for secondary metallurgy. To fill a thin-walled mould, the molten metal must have excellent fluidity, as unfortunately small variations in temperature or alloy composition can increase surface tension: this issue can be even more dramatic if thin-walled castings are combined with recycled alloys. So, if the melt doesn't flow perfectly, macro-defects like misruns (incomplete parts) or cold shuts (where two streams of metal meet, but don't fuse) can be found. So, foundries look for experts in advanced software experts (e.g., ProCAST or MAGMA), as simulations are essential to design complex gating systems that can inject metal fast enough to fill thin sections before they freeze.

In summary, the current industrial focus is centred on secondary metallurgy through perfecting recycling. The primary goal is to mitigate defects caused by contamination and instability, thereby ensuring that the microstructure and mechanical properties of recycled alloys improve to meet the mechanical and microstructural standards of primary materials.

4. Critical Trends by 2030 in Polish Foundries

As we look toward the year 2030, the strategic priorities of the surveyed foundries remain remarkably consistent, reflecting a sector facing a profound transition. The most critical issue identified by industry respondents is the integration of secondary alloys, which received a priority rating of 3.9 out of 5.0. This

high score highlights the industry's focus on the circular economy and the technical necessity of managing recycled melt quality. Closely following this is the digital transformation of the shop floor: the monitoring and control of processes via AI (3.8) and the implementation of Digital Twins (3.5) are viewed as essential pillars for future competitiveness. Giga-castings for automotive applications is a near future technology seen as critical completive strategy (3.5).

Interestingly, ultrathin castings production (thickness ≤ 1.5 mm) is currently viewed as slightly less immediate priorities, scoring 3.0 out of 5.0. This perception likely stems from the significant technical barriers regarding zero-defect production and the tight dimensional tolerances required, suggesting that this specific technology is still maturing. In contrast, thin-walled castings (thickness ≤ 3 mm) are viewed as a more realistic and immediate target, with a relevance score of 3.5, suggesting that Polish foundries view thin-walled production as a viable strategic goal for 2030. Finally, supply chain gaps (2.9) or a lack of certification (3.0) that do not appear as the main problem to the production of thin-walled castings.

4.1. Material and Technology Mapping

The materials identified for these lightweighting initiatives align with the roadmaps previously established in the D4.1 report. Aluminium alloys remain the prevailing choice for lightweight design, cited by 74% of respondents, followed by composites at 63%. Despite currently low production volumes in Poland, magnesium alloys are also seen as a high-potential candidates for future production (59%). Within the heavy alloys sector, thin-walled cast iron is emerging as a strategic focus (52%). Meanwhile, the interest in nickel-base superalloys (52%) confirms a consolidated market where thin-walled castings are already an industrial standard for high-performance components in aviation, airspace and energy production.

In NetCastPL4.0, high-strength Al-Cu alloys have been investigated as substitutes for conventional foundry Al-Si alloys due to their excellent combination of mechanical properties. These alloys are particularly attractive from a European perspective due to their lower content of critical raw materials (Mg, Si) (Study on the critical raw materials for the EU 2023 – Final report). Al-Cu alloys are generally characterized by very good mechanical properties and are currently used, for instance, in aerospace components resistant to long-term fatigue. However, these alloys are technologically difficult to produce, especially in thin-walled castings, because of their high propensity to shrinkage cavities and hot cracking.

In NetCastPL4.0, this defectiveness tendency of Al-Cu alloys has been widely investigated, and the propensity for shrinkage cavities and hot cracking has been dramatically reduced by refining the Al-Cu alloy grains via a fine distribution of TiC, produced through the Self-propagating High-temperature Synthesis in Bath (SHSB). The SHSB method can be easily controlled at the laboratory scale, and actions to bring this technology to a high TRL must be taken. Furthermore, increasing recycling rates with higher scrap content is also a must for future sustainability, as secondary aluminium production requires only about 5% of the energy consumption compared to primary aluminium production from ore. The effects of secondary elements like iron, even in trace amounts coming from scrap, can be detrimental to

microstructure and mechanical properties. Possible corrective actions for these challenges need to be investigated to enable the production of sound Al-Cu thin-walled castings.

Regarding thin-walled cast irons, Austempered Ductile Irons (ADIs) with high specific strength are excellent candidates to substitute some quenched and tempered steels for thin-walled structural applications, such as in heavy transportation, mining machinery, and defence. The stability of the retained austenite is the key issue for the widespread use of these castings, as nowadays few foundries can properly produce stable ausferrite, that is, the ADI microstructure, namely bainitic ferrite with retained austenite where nodular graphite is embedded. The extensive investigation carried out in NetCastPL4.0 on the stability of ausferrite in thin-walled ADIs after thermal and mechanical loading has represented a significant step forward in the comprehension of the chemistry and physics of ADI behaviour, and in the identification of production parameters for different chemical compositions and ADI grades. It is noteworthy that the production of the conventional ductile castings used for the realization of thin-walled ADIs was carried out at Teksid Poland via conventional green sand moulding technology, under the supervision of Dr. Bogdan Cygan who is also a member of the External Advisory Board of the NetCastPL4.0 project. This testifies that thin-walled ADI production in NetCastPL4.0 already occurs at an industrial scale at a high TRL.

Besides ADIs, thin-walled ductile irons for high-temperature applications have also been widely investigated in NetCastPL4.0, gathering paramount information for future applications. Conventional Si–Mo cast iron is widely applied in the automotive industry for the production of exhaust manifolds and turbocharger components, where high resistance to thermal shock and excellent heat resistance are required. In NetCastPL4.0, an innovative Si-Mo cast iron is produced by implementing the Self-propagating High-temperature Synthesis in Bath (SHSB) method to produce thermodynamically stable ceramic phases of TiC. These are homogeneously distributed in the metallic matrix, strengthening it and changing its operational properties. Additionally, it was proved that the titanium despheroidizing effect can help stabilize graphite in the compacted (vermicular) form, widening the cast iron grades that can be produced in NetCastPL4.0. Castings of both conventional Si–Mo iron and the TiC-reinforced Si–Mo composite with compacted graphite were produced with varying wall thicknesses. The new Si–Mo cast iron reinforced with thermally stable TiC particles has been demonstrated to exhibit excellent structural integrity and thermal stability. Furthermore, Ni-Resist ductile irons with high nickel content (typically between 18–36 wt%) have also been investigated in NetCastPL4.0. These materials present an austenitic metallic matrix stable at all temperatures, which makes them suitable for cryogenic and high-temperature applications, along with excellent corrosion resistance. In fact, austenitic cast iron with flake graphite can be used for applications up to 700°C, while those with spheroidal graphite can be used up to 1050°C. This material is commonly used in high-temperature automotive components, such as exhaust manifolds and turbocharger housings, but can be manufactured into components with various wall thicknesses.

To realize light-weight components with complex geometries, the preferred technologies reflect the specific needs of the automotive and aerospace sectors where aluminium alloys are widely used:

- High-Pressure Die Casting (HPDC): Preferred by 85% of respondents for the mass production of automotive components.
- Low-Pressure Die Casting (LPDC): Targeted by 35% for high-precision safety aviation and aerospace components.

Thin-walled castings of ductile irons (ADIs, Si-Mo and Ni-resist Dis) can be produced through conventional gravity casting with green sand technology, while an interesting step forward in the production of ultra-thin-walled ductile iron castings (≤1.5mm) will be via lost-wax technology, which is widely used in nickel-base superalloys for thin-walled components in aviation and energy production. Specialized methods like vacuum-assisted casting (42%) that remains vital for superalloys, while hybrid and composite casting technologies (both 23%) represent the cutting edge of material integration.

Additive Manufacturing (AM): With a 35% interest rate, AM is recognized as a critical technology that will support thin-walled production by enabling complex core geometries and rapid prototyping.

4.2. Overcoming Barriers through NetCastPL4.0

Despite the optimistic outlook, significant barriers remain. The industry is acutely aware of the metallurgical defects (3.8 out of 5.0) associated with thin sections, particularly in conjunction with the secondary metallurgy inherent in recycling challenges (3.7). NetCastPL4.0 addresses the hot-tearing risks of high-strength Al-Cu alloys, caused by high viscosity, wide solidification ranges, stress or strain. These challenges are intensified by the use of recycled scrap, which introduces defect-nucleating tramp elements. In thin-walled castings, extreme thermal gradients further increase rejection rates, necessitating innovative metallurgical solutions. In fact, current EU regulations mandate stringent Circular Economy standards to achieve climate neutrality, requiring a drastic reduction in CO_2 and pollutant emissions across industrial lifecycles, evolving from an environmental preference into a strategic necessity. While transitioning to a circular model can theoretically cut energy consumption by 95% compared to primary production, it introduces significant technical hurdles, primarily due to the chemical inconsistency and uncertainty of scrap-based melts.

Indeed, economical and human factors present also steep hurdles: high capital investment (3.8) and specialized skill gaps (3.8) are seen as the important obstacles to widespread adoption. So, though the foundry industry faces a critical shortage of experts skilled in both advanced alloy design and numerical simulation, this deficit is most evident in thin-walled casting, where rapid cooling and restricted flow defy conventional solidification rules. Without engineers bridging metallurgical thermodynamics and Computational Fluid Dynamics (CFD), the industry remains reliant on costly trial-and-error prototyping, delaying time-to-market.

Next-generation manufacturing, including vacuum-assisted high-pressure die casting (V-HPDC) and hybrid multi-material inserts, is currently bottlenecked by high costs. Although these technologies offer superior mechanical properties, the CAPEX for specialized vacuum systems and advanced tooling often exceeds the

budgets of small-to-medium foundries. Without cost-effective industrialization, these innovations remain confined to high-end niches, preventing the broader automotive and aerospace sectors from leveraging their high-specific-strength potential.

5. Work in Progress

In the following are reported the abstracts of the papers on thin-walled castings that have been published in international magazines, or have been presented in international conferences. Only the abstracts that have not been reported in the previous RoadMap D4.1 are here cited.

Congress of Italian Association of Metallurgy, September 09, 11, 2026 | Brescia, Italy

Advances in the understanding of ausferrite stability in austempered ductile irons

Marcin Górny, Kalle Jalava, Łukasz Gondek, Jan Marosz, Bogdan Cygan, Riccardo Donnini, Dario Ripamonti, Giuliano Angella

This presentation reports the results of research on the behaviour of Austempered Cast Irons (ADIs) within the European NetCastPL4.0 project, which focuses on the production of thin-walled foundry castings to meet European sustainability objectives and reduce harmful emissions and CO_2 production. Starting with studies on the optimization of chemical composition, heat treatment parameters, and casting thicknesses to achieve the best thermal stability of the retained austenite of ausferrite, achieved through diffractometric studies, the mechanical stability of retained austenite was also extensively studied for the same parameters using work-hardening modelling tools. The stability of retained austenite was also explored in greater depth in relation to the thicknesses and geometry of the tensile specimens. An overview of the results and advances in understanding the chemical, physical and mechanical properties of ADIs is reported here.

European Cast Iron Group meeting2026, 28-29 May 2026 - Aalto University – Maarintie 8, 02150 Espoo Finland

Atomic-scale investigation of graphite nodule morphology effects on the mechanical behaviour of ductile iron

Zhao Chenchen, Angella Giuliano

The mechanical behaviour of ductile iron is closely related to the morphology and spatial distribution of graphite nodules. In this study, the tensile response of ferritic ductile irons was investigated through a combined experimental and molecular dynamics (MD) approach. First, tensile tests were carried out on

high silicon ductile iron specimens with different graphite morphologies to characterize the influence of graphite distribution on the macroscopic mechanical response.

To further explore the deformation mechanism at the atomic scale, four ferritic ductile iron supercell models with different graphite sizes and spatial arrangements were constructed based on the LAMMPS platform. Based on these models, uniaxial tensile simulations were performed to investigate the influence of graphite morphology on deformation and damage evolution.

The analysis focused on several key aspects, including fracture behaviour, local stress distribution, atomic-scale stress partitioning, dislocation evolution, and stress triaxiality in the ferrite matrix. In addition, the roles of graphite clustering and refinement in regulating interfacial deformation, load transfer, and the persistence of plastic activity during tensile loading were examined.

This study aims to investigate, from a multiscale perspective, how graphite morphology affects the mechanical behaviour of ductile iron and to establish a mechanistic link between microstructural heterogeneity and macroscopic tensile response. The results are expected to provide useful insights for the microstructural design and performance optimization of ductile iron materials.

TMS2026, March 15-19, 2026 | San Diego, California, USA

Synthesis of A201-TiC in-situ composites via SHSB technology for thin-walled castings

M.Górny, J. Marosz, J. Lelito, M. Kawalec, Ł. Gondek, G. Angella, J. Piątkowski

The aim of the present research was to develop a cast metal matrix composite based on the Al–Cu system, reinforced with titanium carbide (TiC) particles. The A201 aluminium–copper alloy is known for its exceptionally high mechanical strength, particularly after T6 or T7 heat treatment. In this study, the A201 alloy was transformed into a composite material containing varying amounts of TiC (up to 5 wt. %) using the Self-Propagating High-Temperature Synthesis in Bath (SHSB) method.

The research focused on thin-walled castings with wall thicknesses of 3 mm and 5 mm. Particular attention was given to the role of TiC particles in reducing the hot tearing susceptibility (HTS) of the A201 alloy.

Micro and macrostructural evolution, including grain refinement induced by TiC addition, was analyzed using optical and scanning electron microscopy. In addition, X-ray diffraction (XRD) analysis was performed to identify the phase components, lattice parameters changes, and internal strain variations. Numerical simulation of the casting and crystallization processes in a metal mould was also performed to determine the hot tearing capacity of the Al-Cu alloy.

TMS2026, March 15-19, 2026 | San Diego, California, USA

Tailoring carbides morphology in vanadium cast iron

M. Kawalec, M. Górny, A. Przybyło

This article summarizes the characteristics and research on alloyed white cast iron, noted for its excellent mechanical and tribological properties due to carbon forming carbides. Its microstructure is controllable via alloying, cooling rates, modifiers, and spheroidizers, though production is technologically challenging, often needing protective or vacuum atmospheres. High-alloy white irons are vital for abrasion-resistant applications like crushing. They offer high hardness (450-800 HB) but face brittleness, mitigated by elements like silicon and molybdenum.

Recent research on high-vanadium cast iron (9-15% V) explored its microstructure across different compositions. Studies detailed how silicon, cooling rate, and other elements impact vanadium carbide morphology and spheroidization, making this cast iron very ductile, as well as complex carbide crystallization. Controlling the liquid metal's state during casting is crucial. Advanced analytical techniques like optical microscopy, SEM, EDX, WDS, EBSD, and thermal analysis were employed for comprehensive material characterization.

ICCME2025, 27-28 October 2025 – AGH, Faculty of Foundry Engineering, Krakow, Poland

Specimen geometry and tensile testing system effects on the ausferrite stability

Lun Fu, J. Olofsson, M. Schiralli, M. Vedani, M. Gorny, R. Donnini, G. Angella

As in thin-walled foundry products the skin layer becomes dramatically significant respect to the component bulk, defects and metallurgical imperfections can affect the whole component microstructure and properties. This might be even more serious in Austempered Ductile Irons (ADIs), where the main concern of their use is the ausferrite stability, as during thermal and mechanical loading the retained austenite may transform into martensite, causing rupture. In fact, the ausferrite stability depends on chemical segregations and metallurgical defects. So, as the assessment of the ausferrite stability in thin-walled ADI components is paramount, in ICMATE the sensitivity of ausferrite stability to thin-walled tensile specimen geometry has been assessed. Tensile strain hardening analysis has been proved to be a useful tool to assess the ausferrite stability in ADIs.

The results of the investigation on the effect of tensile specimen geometry and tensile gripping system on the tensile mechanical properties of ADIs are reported. Round and flat tensile specimen geometries were used in combination with thread, pin-hole and wedge grips. A Digital Image Correlation (DIC) system was used to collect local information on the stress–strain conditions during tensile testing of flat geometries. Moreover, XRD measurements were carried out to follow the austenite-to-martensite transformation during straining.

ICCME2025, 27-28 October 2025 – AGH, Faculty of Foundry Engineering, Krakow, Poland

Spheroidal graphite in ductile iron: morphology, growth, and distribution

T. Tokarski

Ductile iron is a class of cast iron distinguished by its excellent combination of mechanical strength, ductility, toughness, and wear resistance. Its ability to be cast into complex shapes with both thin and thick sections makes it highly suitable for demanding engineering applications. These superior properties are primarily governed by the presence of graphite nodules, whose size, distribution, and morphology play a crucial role. Despite extensive research, the mechanisms controlling graphite crystallisation remain incompletely understood, particularly the influence of various alloying elements acting directly on spheroidal graphite (SG) formation or through the creation of nucleation sites. This presentation introduces a novel approach for quantifying SG inhomogeneity and provides new insights into the mechanisms of SG formation. In the first part, a statistical method is proposed that defines a single parameter to describe the inhomogeneity distribution of SG particles. The method will be demonstrated using ductile iron castings with varying wall thicknesses. In the second part, the relationship between SG microstructure resulting from nucleation and growth processes will be examined. The complex nature of SG nodules and the intricate graphite/matrix/nucleus interfaces present significant experimental challenges. By employing advanced sample preparation techniques and high-resolution analytical methods such as Transmission Electron Microscopy and Transmission Kikuchi Diffraction, a detailed characterization of the SG microstructure will be presented. The analysis will highlight local variations in crystallinity, ranging from amorphous regions to turbostratic structures and fully crystalline graphite.

ICCME2025, 27-28 October 2025 – AGH, Faculty of Foundry Engineering, Krakow, Poland

Experimental comparison of Al-Si and Al-Cu alloy fluidity in thin-walled sand castings supported by numerical simulations

S. A. Shah, K. Jalava

This study presents an experimental comparison of the fluidity and casting behavior of Al-Si (AlSi10Mg) and Al-Cu (AlCu4Ti) alloys in thin-walled sand castings, in addition to some numerical simulations for optimizing the process. The main objective was to evaluate the influence of temperature and wall thickness on the achievable flow lengths and casting soundness for both alloys. Experiments were performed using Archimedes spiral molds with wall thicknesses ranging in between 1 mm and 5 mm. The results showed that AlSi10Mg exhibited higher fluidity and more complete filling across all tested conditions, while AlCu4Ti displayed limited flow length. The effect of pouring temperature was also studied, revealing that higher temperatures improved the flow in Al-Cu alloy during the experiments. Numerical simulations using MAGMASOFT® were performed in parallel to analyze the impact of different gating configurations, runner tapering, and filter placements on flow uniformity and porosity formation.

These simulations provided valuable insights into how design modifications influence metal flow and defect distribution, supporting the interpretation of experimental results. Overall, the findings confirm that Al-Si alloys offer superior castability and fluidity under thin-walled conditions, whereas Al-Cu alloys require careful optimization of temperature and gating design to achieve defect-free filling.

ICCME2025, 27-28 October 2025 – AGH, Faculty of Foundry Engineering, Krakow, Poland

Si-Mo composite reinforced with (Ti,Mo)C in ultra-thin-walled castings

J. Marosz, M. Górny, R. Cygan, Ł. Rakoczy, G. Angella, M. Kawalec, E. Olejnik

This study focuses on the development and characterization of ultra-thin-walled Si‑Mo ductile iron castings reinforced with titanium‑molybdenum carbides synthesized in situ via the Selfpropagating High-temperature Synthesis in Bath (SHSB) reaction. The objective was to enhance the ductility, toughness, and high-temperature performance of Si‑Mo iron by eliminating detrimental eutectic M_6C carbides and introducing thermodynamically stable (Ti,Mo)C particles. Castings with wall thicknesses as low as 1 mm were successfully produced using the investment casting technique. Metallographic, EDS, and EBSD analyses confirmed the presence of uniformly distributed faceted carbides and excellent casting surface quality.

The results indicate that the incorporation of in-situ synthesized (Ti,Mo)C significantly refines the microstructure and opens new possibilities for ultra-thin-walled castings intended for high-temperature applications. Additionally, the obtained phases exhibited high thermodynamic stability, which potentially translates into improved resistance of the material under high-temperature operating conditions.

ICCME2025, 27-28 October 2025 – AGH, Faculty of Foundry Engineering, Krakow, Poland

An insight into high-nickel austenitic ductile cast iron

M. Bork, M. Górny, Ł. Gondek, G. Angella, J. Morgiel, J. Marosz

The present study focuses on high-nickel ductile cast iron, which is known as Ni-Resist cast iron. The nickel addiction in amount starting from 18 wt.% allows obtaining austenitic metallic matrix into cast iron. Ni-Resist ductile cast iron exhibits combination of the superior properties among which the following must be underlined: possibility to operate in a wide range of temperatures: starting form -200 °C, reaching 1050 °C for grades with spheroidal graphite, corrosion and erosion resistance exceeding unalloyed cast irons and relatively good mechanical properties, especially its plasticity reaching 40%. In the present study the high-nickel ductile cast iron with changing nickel content: 21, 25, 28 and 35 wt.% was examined. Two series having the same nickel content were prepared, where for second series also chromium on the level 2.5 wt.% was added. The micro- and macrostructures were deeply investigated using optical microscopy, scanning electron microscopy including EBSD technique and transmission electron microscopy. The

thermal stability experiments were performed in low and high temperatures by X-ray diffraction (XRD), including cryogenic temperatures. The electrical conductivity of investigated cast irons was examined, science this property is important for some of the applications of Ni-Resist cast iron. Additionally, the mechanical properties of analyzed cast irons were investigated. After that, the chemical composition having 21 wt.% of nickel was selected for section-sensitivity experiments, which were focused on investigations of thin-walled castings.

The results showed predomination of the highly branched dendritic microstructure, with graphite nodules present in the interdendritic regions and along austenite grain boundaries. The conducted research showed that it is possible to obtain a cast iron with elongation reaching 45%, which from point of view of other cast irons grades is unreachable. Also, it was proved that a nickel content on the level 25 wt.% is sufficient to ensure structural stability at cryogenic temperatures.

ICCME2025, 27-28 October 2025 – AGH, Faculty of Foundry Engineering, Krakow, Poland

Evaluation of Sodium Metasilicate Pentahydrate powder as foundry sand binder

N. Anvar, K. Jalava

Sodium silicates are among the most widely used inorganic binders in sand molding for metal casting, yet significant differences in handling, curing, and final casting performance persist across available forms. Liquid sodium silicate binders dominate in current foundry practice, but they pose challenges in transport, storage, and mixing uniformity. To address these limitations, dry silicate powders like sodium disilicate powder has been researched in prior studies, demonstrating favorable molding and final casting characteristics. Building upon this approach, the present study examines sodium metasilicate pentahydrate ($Na_2SiO_3 \cdot 5H_2O$) powder as an alternative binder for sand molding applications. This compound offers several potential advantages like ease of handling, reduced dust generation tendency, rapid solubility in water and better pH regulation ability. Experimental mixtures were prepared using reclaimed silica sands, with systematic variation in both water content and binder concentration to assess their effect on mold strength. In addition, selected formulations were subjected to small-scale casting trials to evaluate mold integrity, dimensional accuracy, and surface finish.

The results indicate that sodium metasilicate pentahydrate can achieve high mold strength through thermal hardening, providing performance comparable to that of conventional industrial binders. These findings suggest that this powder represents a promising alternative for inorganic sand molding in metal casting.

ICCME2025, 27-28 October 2025 – AGH, Faculty of Foundry Engineering, Krakow, Poland

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

K. Major-Gabryś D. Drożyński, M. Górny, J. Marosz, J. Lelito

The production of thin-walled iron castings with complex shape, characterized by high quality while maintaining the required properties, involves many steps in the production process. One of them is the appropriate selection of the technology of molding and core sands, taking into account strict environmental requirements. The need to meet high environmental standards is currently the dominant factor in the development of molding sands technologies is. It's even being done at the expense of reducing the technological properties of the materials. As part of the development of molding compounds for thin-walled castings, two compounds with organic binders and two compounds with inorganic binders were tested. Tests were carried out on the tensile and bending strength, permeability, and friability of the compounds. For selected molding sands, tests were carried out on their thermophysical properties (hot distortion parameter), gas emission, and thermal degradation. Molds were also made using 3D printing technology and no-bake system.

The tests carried out on the molding sands showed that all the proposed mixtures have the appropriate properties for the production of thin-walled castings. Sands with inorganic binders are characterized by lower gas emission, which is important both from the point of view of environmental protection and the quality of the castings obtained. As part of the work, a mold for the production of thin-walled castings was designed. The molds were made from molding compounds selected for testing. Four castings with different wall thicknesses were made in each mold. The feeding system was designed on the basis of computer simulation.

PROJECT CONFERENCE

International Scientific Conference of Polish, Czech and Slovak Foundrymen 2026, April 20-22, 2026 | Grodków, Poland

A201–TiC in-situ composites produced by SHSB technology for thin-walled castings

M.Górny, J. Marosz, J. Lelito, M. Kawalec, Ł. Gondek, G. Angella, J. Piątkowski

The present study aimed to develop a cast metal matrix composite based on the Al–Cu system reinforced with titanium carbide (TiC) particles. The A201 aluminium–copper alloy is known for its exceptionally high mechanical strength, particularly after T6 or T7 heat treatment. In this work, the A201 alloy was converted into a composite material containing different amounts of TiC particles (up to 5 wt. %) using the Self-Propagating High-Temperature Synthesis in Bath (SHSB) method.

The investigations were carried out on thin-walled castings with wall thicknesses of 3 mm and 5 mm. Special attention was paid to the influence of TiC particles on the hot tearing susceptibility (HTS) of the A201 alloy.

The evolution of the micro- and macrostructure, including grain refinement resulting from TiC addition, was examined using optical microscopy and scanning electron microscopy. Furthermore, X-ray diffraction (XRD) analysis was performed to identify the phase constituents as well as to evaluate changes in lattice parameters and internal strains. Numerical simulations of casting and solidification in a metal mold were also conducted to assess the hot tearing tendency of the Al–Cu alloy.

PROJECT CONFERENCE

International Scientific Conference of Polish, Czech and Slovak Foundrymen 2026, April 20-22, 2026 | Grodków, Poland

The impact of Binder Jetting (3D printing) technology on the ecological and economic aspects of producing casting molds and cores from self-hardening molding sands with furfuryl resin

K. Bernaś, K. Major-Gabryś

The modern foundry industry is currently balancing the need for rapid technological innovation with increasingly stringent environmental regulations. Traditional molding processes based on furfuryl resin-bonded sands are known to emit harmful volatile organic compounds and polycyclic aromatic hydrocarbons, while also creating significant waste management costs due to the toxicity of used sand reclamation residues.

Binder Jetting technology emerges as a transformative alternative, offering the ability to produce highly complex sand molds and cores directly from digital CAD models. This additive approach eliminates the need for traditional patterns, reduces process time, and enhances geometric precision, while also allowing for the early integration of solidification simulations.

From an economic standpoint, Binder Jetting is particularly advantageous for prototyping and the manufacturing of intricate, low-volume castings where design flexibility outweighs the higher unit costs typical of additive processes. In contrast, traditional methods remain the standard for mass production due to their lower unit costs. Ultimately, achieving sustainable manufacturing in the foundry sector depends on optimizing the trade-off between the design freedom provided by 3D printing and the economic and environmental imperatives of waste reduction and emission control.

PROJECT CONFERENCE

International Scientific Conference of Polish, Czech and Slovak Foundrymen 2026, April 20-22, 2026 | Grodków, Poland

ADI Cast Iron – the material of the future

B. Cygan, M. Górny, G. Angella, K. Jalava, Ł. Gondek, J. Marosz

Austempered Ductile Iron (ADI) is increasingly recognized as a strategic structural material for modern engineering, offering a superior combination of high strength, ductility, and fatigue resistance. These

properties make it a compelling, lightweight alternative to forged and cast steels, particularly in the automotive and heavy-duty sectors. The exceptional performance of ADI is derived from its unique ausferritic microstructure, consisting of bainitic ferrite and high-carbon austenite. This research evaluates the influence of chemical composition—specifically nickel and copper additions—and processing parameters on the stability and mechanical behavior of ADI, with a focus on thin-walled castings.

The study demonstrates that achieving optimal properties requires precise control over the austenitizing temperature, which dictates carbon distribution and the stability of the retained austenite. Experimental results indicate that an optimal austenitizing range of 820–840°C produces a refined microstructure with stable austenite, ensuring high impact toughness and ductility even under cryogenic conditions. In contrast, higher temperatures lead to coarser structures and the formation of "blocky" austenite, which is prone to transforming into brittle martensite under mechanical stress or low temperatures, significantly deteriorating the material's performance.

Furthermore, the research highlights the critical role of section thickness in phase transformation kinetics. Thin-walled castings (3–5 mm) exhibit a higher density of graphite nodules, which promotes faster carbon diffusion and results in a more refined, stable structure compared to thicker sections. This refinement provides enhanced resistance to martensitic transformation, making thin-walled ADI particularly suitable for high-performance, weight-sensitive applications. By combining advanced metallurgical design with industrial scalability, ADI positions itself as a key material for next-generation engineering systems, balancing mechanical excellence with the demands of modern lightweight construction.

PROJECT CONFERENCE

International Scientific Conference of Polish, Czech and Slovak Foundrymen 2026, April 20-22, 2026 | Grodków, 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

D.M. Halejcio, K. Major-Gabryś, J. Marosz, M. Górny, A. Fijołek

The quality of the surface layer in aluminium alloy castings is a decisive factor for their functional performance, affecting corrosion resistance, fatigue strength, and dimensional accuracy. While traditional organic binders dominate the foundry industry due to their excellent technical properties, they pose significant environmental risks, including high gas emissions during pouring and toxic residues in post-regeneration dust. This study explores inorganic binders, specifically those modified for Binder Jetting (BJ) technology, as an eco-friendly alternative that aligns with modern additive manufacturing trends.

The research compared three types of binders: a standard furfuryl resin (FK), commercial hydrated sodium silicate (A), and a modified inorganic binder designed for 3D printing (A3D). Experimental results revealed that the binder type significantly influences the thermal characteristics of the mold and the final casting quality. The organic binder (FK) exhibited the highest gas generation (over 1400 ml/g), which negatively

impacted the casting's surface, leading to increased roughness and lower microhardness. In contrast, the inorganic binders (A and A3D) reduced gas emissions by nearly 70%, significantly improving the working environment and casting integrity.

The study highlights that the A3D-modified inorganic binder provided the most favorable results, ensuring the highest and most consistent microhardness values and superior surface quality (lowest Ra and Rz parameters). These findings confirm that inorganic binders tailored for Binder Jetting technology not only meet ecological standards by minimizing harmful emissions but also enhance the metallurgical properties of Al–Si alloys. Consequently, this technology serves as a viable solution for high-precision industries like aerospace and automotive, where surface integrity and environmental sustainability are paramount.

PROJECT CONFERENCE

International Scientific Conference of Polish, Czech and Slovak Foundrymen 2026, April 20-22, 2026 | Grodków, Poland

Chemical hardening of solid inorganic foundry binder

Nurul Anwar, Kalle Jalava

In the pursuit of sustainable manufacturing, the foundry industry is increasingly turning to inorganic sodium silicate binders to replace traditional organic systems. Unlike organic resins, which emit volatile organic compounds (VOCs) and harmful odors during pouring, inorganic binders are environmentally friendly and produce no hazardous emissions. This research explores a novel approach by utilizing the solid form of these binders (sodium disilicate powder), which offers significant logistical advantages, including easier transport, stable storage, and potential simplification of 3D printing processes for sand molds.

While sodium silicates are traditionally hardened through physical dehydration (heat) or CO_2 gas, this study investigates chemical hardening using liquid esters. This "no-bake" approach is highly desirable for industrial scalability as it eliminates the need for expensive and time-consuming heating processes. The research tested four different chemical hardeners (esters) typically used for liquid silicates to determine their functional effectiveness when applied to a solid silicate-sand matrix.

Results confirm that ester-based hardeners can successfully initiate and sustain the hardening reaction in solid silicate systems. Although the 24-hour bending strengths achieved were lower than those produced by physical dehydration—a trend consistent with traditional liquid silicate systems—the molds exhibited smooth surfaces and sufficient structural integrity for casting trials. The study highlights that while the process is technically viable, further optimization of the hardener-to-binder ratio is essential to develop a uniform silica network and maximize mechanical strength. Ultimately, the use of solid inorganic binders combined with chemical hardening represents a strategic step toward fully "green" foundry operations, balancing process efficiency with environmental responsibility.

PROJECT CONFERENCE

International Scientific Conference of Polish, Czech and Slovak Foundrymen 2026, April 20-22, 2026 | Grodków, Poland

Effect of (Ti, Mo)C particles on the microstructure and thermophysical properties of compacted graphite iron castings

J. Marosz, M. Górny, R. Chulist, J. Morgiel, M. Kawalec, G. Angella, R. Gałek, R. Zapała, M. Tupaj

Modern foundry engineering is increasingly focused on transforming traditional alloys into volume-reinforced composites to meet the automotive industry's demand for high-strength, lightweight, and thin-walled components. Compacted Graphite Iron (CGI) is particularly valued for its balanced thermophysical properties, but stabilizing its microstructure in thin sections remains a technical challenge. This study investigates the use of the Self-Propagating High-Temperature Synthesis in Bath (SHSB) method to produce silicon-molybdenum (Si–Mo) cast iron composites reinforced with in-situ formed (Ti, Mo)C carbides.

The SHSB process involves introducing Ti and C briquettes into the liquid metal, leading to the formation of finely dispersed, thermodynamically stable carbides. Research results indicate that these carbides effectively stabilize vermicular graphite even in thin-walled castings (5 mm) while suppressing the formation of brittle molybdenum carbides at grain boundaries. Unlike traditional titanium alloying, this in-situ synthesis does not deplete the graphite fraction because carbon is supplied directly via the SHSB reaction, ensuring a high-quality ferritic matrix with a favorable graphite morphology.

Thermophysical and chemical analyses highlight the superior performance of the Si–Mo/TiC composite. It maintains high thermal conductivity—comparable to conventional CGI—while exhibiting significantly enhanced oxidation resistance at 600°C and 800°C. This improvement is attributed to the high stability of the (Ti, Mo)C phases and the formation of a protective passive surface layer. Ultimately, the study confirms that SHSB-reinforced Si–Mo cast iron offers a strategic solution for components subjected to extreme thermal and mechanical loads, such as turbochargers and exhaust manifolds, by providing exceptional structural stability and resistance to oxygen diffusion.

PROJECT CONFERENCE

International Scientific Conference of Polish, Czech and Slovak Foundrymen 2026, April 20-22, 2026 | Grodków, Poland

Structural stability assessment of high-alloyed abrasion-resistant white cast iron

M. Górny, M. Kawalec

White cast irons are indispensable in mining and power engineering, where components must endure extreme abrasive wear. Traditionally, high-chromium cast irons are used for these applications, but they involve high production costs. This study evaluates the optimization of hypoeutectic white cast iron by

introducing strategic alloying additions of titanium, chromium, and vanadium, alongside tellurium as a modifier, to achieve superior structural stability and wear resistance at a lower cost.

The research compared a base melt with three modified variants. The results demonstrate that the synergy of Ti, Cr, and V promotes the formation of hard M_3C and M_7C_3 type carbides and refines the pearlitic matrix. A critical finding is the role of tellurium; as a surface-active element, it acts as an effective modifier that fragments cementite and carbide phases. This leads to a more uniform distribution of hard precipitates, significantly reducing the risk of brittle fractures and enhancing the material's overall durability.

Structural stability tests involving a two-step heat treatment (quenching and tempering) confirmed that the alloyed samples maintain a fine-grained matrix and high dispersion of hard phases. Abrasive wear resistance tests, conducted according to the Miller method, showed a measurable reduction in wear rates for the modified alloys. The optimized melt (Ti+Cr+V) achieved the best performance. The study concludes that precisely controlled alloying and modification allow for the production of white cast irons with hardness and wear resistance comparable to high-alloyed grades while maintaining significantly better production economics.

19th International French-Polish Conference on Reactivity of Solids, 22-24 April 2026, Arts et Métiers Institute of Technology, Cluny, France

Thermal stability of austempered ductile iron

M. Górny, G. Angella, K. Jalava, Ł. Gondek, J. Marosz, B. Cygan

Thermal stability of austempered ductile iron (ADI) at low and subzero temperatures is a key factor determining its applicability in dynamically and thermally loaded components operating under severe environmental conditions. This study focuses on the role of heat treatment parameters in controlling the stability of high-carbon austenite against martensitic transformation at temperatures below 0 °C. Particular attention is paid to the influence of the austenitization stage, which is often underestimated, while the austempering conditions were kept constant.

Experimental investigations were carried out on ADI castings with wall thicknesses ranging from 3.0 to 13.0 mm, austenitized at temperatures between 800 °C and 900 °C. The thermal stability of the ausferritic microstructure was assessed using X-ray diffraction (XRD) measurements performed over a wide temperature range, from cryogenic conditions (20 K) up to room temperature. Phase fractions, lattice parameters, and carbon content of retained austenite were determined to evaluate its stability under cooling and to identify the onset of martensitic transformation. Complementary static and dynamic mechanical tests were conducted to correlate microstructural stability with mechanical performance.

The results demonstrate that the resistance of high-carbon austenite to transformation at subzero temperatures strongly depends on the austenitization temperature through its effect on austenite grain

size, chemical homogeneity, and carbon distribution. Thin-walled castings exhibited enhanced structural homogeneity and superior thermal stability compared to thicker reference castings, showing a reduced tendency for low-temperature martensitic transformation. The study confirms that appropriate control of the austenitization stage is critical for achieving high thermal stability of ADI at temperatures below 0 °C, thereby extending its safe application window in low-temperature and cryogenic environments.

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The influence of modified inorganic binders intended for 3D printing on selected properties of thermally cured moulding sands – conventionally and with microwaves

Dawid M. Halejcio, Katarzyna Major-Gabryś

This study determined the impact of thermal curing on the basic properties of moulding compounds made with commercial inorganic binders and binders based on them, modified for use in 3D printing technology (Binder Jetting). Two inorganic binders based on sodium silicate and a binder based on aluminosilicates were tested. As part of the work, the parameters for thermal curing of the mixtures were selected: for curing in a dryer, the best properties were obtained for mixtures containing 2.0 p.p.w. of binder cured for 10 min at 160°C. In the case of microwave curing, the best properties were obtained for moulding sands containing 2.0 p.p.w. of binder cured for 6 min at a device power of 800 W. The tests showed that the basic properties of moulding compounds with binders developed on the basis of commercial binders for use in 3D printing technology, thermally cured in a dryer, do not differ significantly from the properties of compounds with commercial binders. In the case of microwave curing, a reduction in the strength of compounds with new binders was observed in relation to compounds with classic binders. Thermal deformation tests of compounds with classic and modified binders confirmed the typical behavior observed for inorganic systems. It was proven that new, modified inorganic binders developed for 3D printing of moulds and cores using Binder Jetting technology can be used as binding materials in thermally cured moulding sands. Both thermal curing methods were assessed as suitable for curing moulding compounds with new binders.

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Structure and Thermophysical Characteristic of Compacted Graphite Cast Iron Composite Castings Reinforced with (Ti, Mo)C

Jan Marosz, Marcin Górny, Robert Chulist, Jerzy Morgiel, Magdalena Kawalec, Giuliano Angella, Rafał Gałek, Renata Zapała and Miroslaw Tupaj

This work deals with the development of new Compacted Graphite Cast Iron Composite Castings as an alternative to Si–Mo ductile iron. The new material is a silicon-molybdenum cast iron (Si–Mo), transformed into a cast composite using the Self-propagating High-temperature Synthesis in Bath (SHSB) method, which synthesizes ceramic carbide particles of metals such as Ti, W, Nb, Mo, Zr. SHSB is used to ensure the formation of thermodynamically stable ceramic phases, in this case, carbide phases. Among the listed metals, titanium was selected for the SHSB synthesis process due to the exceptionally favorable physicochemical properties of titanium carbide and its highly exothermic enthalpy of formation. The described process strengthens the matrix of the material, changing its characteristic operational properties. The resulting composite is designated as Si–Mo TiC. Conventional Si–Mo cast iron is widely applied in the automotive industry, where it is used, for instance, in the production of exhaust manifolds and turbocharger components, where high resistance to thermal shock and excellent heat resistance are required. Transforming this material into a composite material improves many physicochemical parameters. Additionally, titanium desferoidizing effect helps stabilize graphite in the compacted (vermicular) form. Castings of both conventional Si–Mo iron and the TiC-reinforced Si–Mo composite with compacted graphite were produced with varying wall thicknesses. The microstructural characteristics and thermophysical properties, such as thermal conductivity and thermal stability, of the classical and composite materials were compared. The new Si–Mo cast iron reinforced with thermally stable TiC particles has been demonstrated to exhibit excellent structural integrity and thermal stability.

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The evaluation of thermal stability, electric conductivity and carbide morphology of austenitic ductile iron castings

Magdalena Bork, Marcin Górny, Łukasz Gondek, Jerzy Morgiel, Krzysztof Morgiel

The Ni-Resist ductile iron, with a nickel content ranging from 18% to 36%, is a material designed for service under extreme conditions. One of the main objectives of this study was to determine the minimum nickel content required to stabilize the austenitic structure at cryogenic temperatures. Additional aims included investigating structural features related to the solidification of austenite dendrites, graphite nodules, and eutectic carbides. Moreover, the electrical conductivity, which is critical for certain applications of Ni-Resist ductile irons, was also examined. To this end, castings with varying nickel content (21%, 25%, 28%, and 35%) and with or without chromium additions were prepared. Microstructural characterization was performed using optical, scanning, and transmission electron microscopy, X-ray diffraction (XRD), and electrical conductivity measurements.

The results showed that a highly branched dendritic microstructure predominates, with graphite nodules located in interdendritic regions and along austenite grain boundaries. In chromium-alloyed ductile irons, the austenitic matrix contains Cr = 1.7 ± 0.3 wt.% in the vicinity of M_7C_3-type eutectic carbides. Furthermore, thermal stability analysis indicated that a minimum nickel content of 25 wt.% is sufficient to

ensure structural stability at cryogenic temperatures down to 25 K. Finally, complementing the above-mentioned investigations, the electrical conductivity characteristics of the studied high-nickel austenitic cast irons were determined.

Polymers (2025); https://doi.org/10.3390/polym17212920

The influence of furfuryl resin type—classical and designed for sand 3D printing—on cast iron casting microstructure and surface roughness

Katarzyna Major-Gabryś, Dawid Halejcio, Andrzej Fijołek, Jan Marosz, Marcin Górny

Resin-based binders are one of the main materials used in foundry moulding and core sands. Self-curing sand with furfuryl resin is one of the most popular technologies in the production of moulds and cores for complex, critical castings made of iron and non-ferrous alloys. It has dominated small-batch production and the production of large-sized castings. This work is part of the research on new molding sands for mold additive manufacturing (3D printing). Three-dimensional printing technology in the production of sand-casting molds and cores is finding increasing industrial application in the production of castings from non-ferrous metal alloys. The aim of the research presented in this paper was to determine the influence of furfuryl resin type (classical and designed for 3D printing of sand molds) on cast iron casting properties. The pouring parameters were elaborated on the basis of the MAGMA software. Microscopic observations of castings, produced in classical and 3D-printed molds, were conducted, as well as an assessment of the roughness of the samples. The gas emissions from molding sands with both types of furfuryl resin were tested and analyzed in the context of the roughness of the castings obtained. It was proven that molding sand with furfuryl resin designed for 3D printing was characterized by lower gas emissions, which, in the case of moulding sands with organic binders, is beneficial from an environmental point of view.

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The impact of wall thickness on the microstructure and mechanical properties of austenitic high-nickel ductile iron

Magdalena Bork, Marcin Górny, Giuliano Angella, Jan Marosz

Austenitic ductile iron belongs to the cast iron group characterized by high nickel content, ranging from 18% to 36% by weight, which allows the formation of an austenitic metallic matrix. As a consequence, this cast iron group exhibits a combination of highly beneficial properties allowing utilization under extreme conditions and justifies the increased price of these cast iron grades. Some of the applications require complex castings with changing geometry and wall thicknesses. For this reason, the main objective of this study was to determine the possibility of obtaining castings with various degrees of wall thickness,

including thin-walled: 3 mm, 5 mm, 13 mm and 25 mm, and good quality microstructures without defects as well as with mechanical properties on a similar level. For our investigations the austenitic ductile cast iron grade EN-GJSA-XNi22 was selected. Material characterization was carried out using optical microscopy, and static tensile test measurements. Additionally, the thermal analysis during crystallization was also determined. The investigations showed the highly homogeneous mechanical properties of castings with various wall thicknesses. The main differences in the microstructure parameters concerned the number and diameter of the graphite nodules.

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Influence of the addition of tellurium and heat treatment on the microstructure of hypoeutectic white cast iron

Alicja Trela-Przybyło, Magdalena Kawalec, Marcin Górny

The primary challenge in industries such as mining and power engineering is ensuring high resistance to abrasive wear. While high-chromium cast irons are traditionally used for these purposes, they incur significant production costs. This study explores the optimization of hypoeutectic white cast iron modified with alloying elements such as titanium, chromium, and vanadium, specifically focusing on the role of tellurium as a modifier and the impact of a two-step heat treatment on structural stability.

Microstructural analysis revealed that tellurium acts as a potent surface-active modifier that fundamentally alters the morphology of cementite and carbide phases. Its introduction causes these hard phases to fragment, resulting in a more uniform and refined distribution throughout the matrix. This structural shift is critical for improving mechanical performance, as it minimizes the risk of brittle fracture and enhances overall resistance to abrasive wear.

The application of a two-step heat treatment (quenching and tempering) further augmented these effects by refining the grain size of the matrix and promoting phase stability. The synergy between tellurium modification and heat treatment produced a superior microstructure characterized by highly dispersed hard phases within a fine-grained matrix. These findings confirm that the combination of strategic alloying and tellurium modification allows for the production of durable components with properties comparable to high-alloyed grades while maintaining significantly better production economics.

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Effect of titanium on structural, mechanical and functional properties of thin-walled CGI castings

M. Kawalec, M. Górny, J. Kozana, J. Marosz

Compacted Graphite Iron (CGI) is an increasingly vital material in the automotive industry, combining the advantages of gray iron (good thermal conductivity and vibration damping) with those of ductile iron (high strength). However, stabilizing graphite morphology in thin-walled castings remains a significant challenge, as high cooling rates typically promote graphite spheroidization or the formation of hard white iron structures. This study analyzes the role of titanium as a key alloying addition that counteracts spheroidization and stabilizes the vermicular form of graphite, particularly in sections with small wall thicknesses.

The research involved analyzing thin-walled castings with thicknesses ranging from 3 to 25 mm under varying titanium contents. The results confirm that titanium effectively inhibits the action of spheroidizing elements (such as magnesium), allowing for the maintenance of a high fraction of compacted graphite even during rapid solidification. Additionally, titanium promotes the formation of hard and thermodynamically stable titanium carbides and nitrides. When dispersed within the ferritic-perlitic matrix, these particles significantly influence the functional properties of the material.

The analysis of mechanical properties demonstrated that a properly selected titanium content allows for high strength while maintaining favorable technological properties. However, excessive titanium can lead to the agglomeration of carbides, which negatively affects the machinability of the material. The paper emphasizes that precise metallurgical control and an understanding of the interaction between titanium and cooling rates are essential for producing high-quality automotive components with variable geometries. In conclusion, titanium serves as an effective tool for shaping the microstructure of thin-walled CGI, enabling the weight reduction of castings while maintaining the required operational durability.

6 Exploitation Actions: NetCastPL4.0 Initiative

The gaps for thin-walled castings exploitation have been categorised to propose actions to bridge them.

6.1. Light-Weight Castings for High-Performance Al-Cu and Ductile Irons

6.1.1. The Challenge of Castability and Circularity

In the framework of the NetCastPL4.0 project, the development of high-specific-strength Al-Cu alloys faces significant metallurgical hurdles. These alloys are notorious for their high propensity for hot tearing. This phenomenon is driven by a combination of high melt viscosity and a wide solidification range, which creates fragile mushy zones during the final stages of cooling.

The challenge is further compounded by the industry's shift toward circularity. Incorporating secondary alloys from recycled scrap introduces tramp elements and contaminants that act as nucleation sites for defects, significantly increasing the risk of structural failure. In thin-walled castings, where thermal gradients are most extreme, these issues lead to unacceptable rejection rates in conventional casting processes.

6.1.2. Solidification Control in Light-Weight Sections

There is a critical technological gap in mitigating hot tearing in aluminium alloys while simultaneously managing the complex microstructures of ductile irons. Specifically, in Si-Mo (Silicon-Molybdenum) nodular and compacted graphite irons (CGI) used for high-temperature applications, thin-walled sections present a unique difficulty.

In conventional Si-Mo castings, molybdenum tends to segregate into the last zone to freeze (LZF), leading to the formation of coarse primary Mo-rich carbides. These brittle interdendritic phases are highly deleterious, as they serve as crack initiation sites under thermo-mechanical fatigue. Current market standards struggle to achieve a uniform distribution of these carbides in complex geometries, limiting the performance of components like exhaust manifolds and turbocharger housings.

6.1.3. Scaling SHSB-TiC Technology to TRL 7

To address these gaps, the NetCastPL4.0 project has deployed an innovative solution: Self-propagating High-temperature Synthesis Bath (SHSB) applied via TiC (Titanium Carbide). This technology serves as a potent grain refiner for Al-Cu alloys. TiC particles in Al-Cu alloy act mainly as growth inhibitors during crystallization, which resulted in strong grain growth restriction, in contrast to the AlTi5B1 grain refinement, where refinement is primarily due to heterogeneous nucleation of α-Al dendrites. The SHSB-TiC carbides promote a transition from a coarse dendritic structure to a fine, equiaxed grain morphology. This refinement drastically reduces the hot tearing propensity, allowing for the successful casting of high-strength, thin-walled aluminium components even when using secondary materials.

The same SHSB-based innovative inoculation technology has been applied to SiMo ductile irons with exceptional results. It facilitates a fine and highly uniform distribution of carbides throughout the matrix, preventing the harmful segregation typically seen in thin sections. This microstructural homogenization significantly enhances the material's durability in high-temperature environments.

Currently, these advancements have been validated at TRL 4 (Laboratory Scale), demonstrating proof-of-concept in controlled environments. The ultimate objective of NetCastPL4.0 is to transition this technology to TRL 7 (System Prototype Demonstration) before the project's conclusion. This move to an operational level will prove the industrial reliability of SHSB-TiC refinement, enabling the mass production of high-performance, circular-ready alloys for the automotive and aerospace sectors.

6.2. Engineering the Future of Light-Weight Castings

6.2.1. Specialized Expertise in Advanced Metallurgy

The modern foundry industry is facing a significant workforce challenge: a shortage of skilled personnel capable of crossing the intersection of advanced alloy design and complex numerical simulations. This deficit is particularly acute when dealing with thin-walled sections, which are increasingly demanded by the automotive and aerospace sectors to reduce vehicle weight and carbon footprints.

Designing these sections is very challenging because they do not follow the same solidification rules as bulkier components. In thin-walled casting, rapid cooling rates and restricted metal flow create extreme thermal gradients, leading to defects that traditional design methods cannot easily predict. Without engineers who possess a deep, dual understanding of both metallurgical thermodynamics and computational fluid dynamics (CFD), the industry struggles to move beyond trial-and-error prototyping, resulting in high costs and delayed time-to-market.

6.2.2. Trust Deficit in Digital Twins and AI

While the technological horizon offers powerful tools like Digital Twins and Artificial Intelligence (AI) to address these complexities, a significant implementation gap remains. Digital Twins, that is, virtual replicas that mirror a physical casting process in real-time, and AI-driven predictive models have the potential to revolutionize how hot tearing or porosity can be anticipated. However, these tools are new and often viewed with scepticism by traditional industry experts.

There is a lack of trust in black-box AI models that cannot always explain the "why" behind a predicted failure. Furthermore, even when the software is available, there is a severe skills gap. Most current engineers have not been trained to integrate high-dimensional data streams from sensors into a coherent Digital Twin. So, even if the industry has the data and the potential tools to solve the thin-wall problems, there is a lack of specialized human capital to build, validate, and trust these digital architectures.

6.2.3. Generative Design

The strategic target for the NetCastPL4.0 project is to shift the industry paradigm toward Generative Design and Topology Optimization specifically tailored for casting. Unlike traditional design, where an engineer draws a part and checks its castability, Generative Design uses AI algorithms to explore thousands of design iterations based on performance requirements and manufacturing constraints.

In NetCastPL4.0, we have bridged the gap between digital theory and physical reality by investigating innovative solutions for grain refinement and microstructural homogenization. By using SHSB-processed TiC, we have demonstrated that we can control the metallurgy at a fundamental level. These metallurgical breakthroughs provide the reliable data needed to feed Generative Design tools.

The ultimate goal is to create a seamless workflow where these investigated solutions are implemented into user-friendly design and simulation platforms. By embedding metallurgical intelligence into the software, we can empower a new generation of engineers to perform complex simulations with higher confidence. This approach not only solves the thin-wall challenge but also provides a clear roadmap for achieving TRL 7, transforming "untrusted" digital tools into vital assets for high-performance, sustainable casting.

6.3. Circular Metallurgy in Light-Weight Castings

6.3.1. Circularity and Decarbonization

Under current European Union regulations, research and innovation projects are now bound by stringent Circular Economy requirements aimed at achieving climate neutrality. The primary objective is a drastic reduction in CO_2 and pollutant emissions across the entire industrial lifecycle and final products applications. For the metallurgical sector, this shift makes the adoption of secondary metallurgy, that is, the melting and refining of recycled scrap, so it is not merely an environmental preference but a strategic necessity.

Traditional primary production of aluminium and ferrous alloys is energy-intensive and carries a heavy carbon footprint. By transitioning to a circular model, the industry can theoretically reduce energy consumption by up to 95%. However, this transition is troubled with technical hurdles. The reliance on secondary raw materials introduces high levels of uncertainty into the melt, as the chemical consistency of scrap is far inferior to that of primary ingots.

6.3.2. The Downcycling Trap and Contamination Control

A significant technological gap exists in the effective recycling of multi-material castings and specialized, high-performance alloys. In the current state of the art, it is extremely difficult to recycle these complex components without severely degrading their mechanical and physical properties. This phenomenon, often called downcycling, occurs because secondary melts are frequently contaminated with tramp

elements (such as iron in aluminium or copper in steel and cast irons) that cannot be easily removed during standard remelting.

These contaminants lead to a cascade of material and process defects, including increased porosity, reduced ductility, and a significant susceptibility to hot tearing, especially in the thin-walled sections. Furthermore, the presence of non-metallic inclusions and oxides from scrap surfaces compromises the structural integrity of the final part. There is a lack of robust, industrial-scale methods to neutralize these impurities or to clean the secondary melt effectively enough to meet, for instance, the rigorous standards of the automotive and aerospace industries.

6.3.3. Mitigation Technologies for High-Quality Secondary Casting

The primary target of the NetCastPL4.0 project is to develop and validate a reliable pathway for high-quality secondary metallurgy that does not sacrifice performance for circularity. The focus is on finding innovative mitigation methods to counteract the negative effects of scrap-derived contaminants.

A key pillar of this strategy is the implementation of advanced grain refinement and melt inoculation technologies. By using eg. SHSB-processed TiC carbides, the ways to force a favourable microstructure even in the presence of impurities, have been investigated. These refined microstructures help to sequester contaminants at the grain boundaries in a less harmful morphology, thereby reducing the propensity for cracks and defects.

Ultimately, the goal is to provide a comprehensive toolkit for foundries that includes melt-cleaning protocols and microstructural homogenization techniques. By achieving this, NetCastPL4.0 aims to demonstrate that secondary alloys can match the performance of primary materials, moving the technology toward TRL 7 and ensuring that the European casting industry remains competitive in a zero-emission future.

6.4. Scaling Light-Weight Castings

6.4.1. The High Barrier to Entry for Light-Weight Advanced Castings

The transition toward next-generation manufacturing that incorporates concepts such as vacuum-assisted high-pressure die casting (V-HPDC) and hybrid multi-material inserts, is currently bottlenecked by significant economic hurdles. While these technologies offer superior mechanical properties and weight reduction, they are notoriously expensive to scale. The capital expenditure (CAPEX) required for specialized vacuum systems, advanced tooling, and the integration of hybrid ceramic or metallic inserts often exceeds the budgetary constraints of traditional small-to-medium foundry operations. Without a clear path to cost-effective industrialization, these innovations remain confined to high-end niche applications, preventing the broader automotive and aerospace sectors from benefiting from their high-specific-strength potential.

6.4.2. Rejection Rates and the NDT Deficit

A critical technical gap exists in the reliability of manufacturing ultra-thin-walled components. When attempting to push the limits of thin-section casting, foundries face prohibitively high rejection rates (scrap). These defects that range from cold shuts and gas porosity to misruns, are often worsen by the very technologies intended to fix them, as the process window becomes extremely narrow.

Furthermore, there is a distinct lack of automated Non-Destructive Testing (NDT) solutions specifically optimized for lightweight, complex-geometry parts. Conventional X-ray or ultrasonic testing is often too slow or lacks the resolution required to detect micro-defects in thin sections at industrial speeds. This absence of real-time, automated quality assurance means that defects are often only discovered after expensive post-processing or, worse, during service, creating a massive financial risk that discourages the adoption of advanced casting methods.

6.4.3. Technical and Business Schools

The strategic target of the NetCastPL4.0 project is to bridge these gaps by establishing a comprehensive training school designed to upskill the next generation of industry leaders. This initiative is unique because it addresses both the technical and business dimensions of advanced metallurgy.

On the technical side, the curriculum focuses on mitigating the high scrap rates associated with thin-walled castings by teaching the implementation of investigated grain refinement and homogenization techniques. This includes training on how to optimize vacuum parameters and hybrid insert placement to ensure structural integrity.

On the business side, the NetCastPL4.0 project with the business school will provide the tools for economic feasibility modelling. This empowers engineers and managers to calculate the true Return on Investment (ROI) of advanced technologies, accounting for the reduction in scrap and the long-term energy savings of lightweight components. By fostering a workforce that is equally proficient in metallurgical engineering and operational management, NetCastPL4.0 aims to transform these expensive concepts into a reliable, TRL 7-standard reality for the European circular economy.

7. Conclusions: The Future of Light-Weight Castings

The NetCastPL4.0 project represents a transformative leap in the thin-walled foundry sector, providing a robust response to the dual challenges of technical performance and environmental sustainability. As moving toward the 2030 roadmap, the conclusions drawn from this project underline a fundamental shift in how advanced alloys are designed, processed, and scaled within a circular economy. By bridging the gap between laboratory-scale innovation (TRL 4) and operational industrial reliability (TRL 7), NetCastPL4.0 has established a new pattern for high-specific-strength materials that are essential for the next generation of aerospace and automotive engineering.

At the core of this success is the mastery of solidification science in thin-walled sections. The project has demonstrated that the historical low resistance to hot cracking of Al-Cu alloys and the deleterious segregation in SiMo ductile irons are no longer insurmountable barriers. Through the strategic application of Self-propagating High-temperature Synthesis (SHSB) and TiC inoculation, it has been proven that microstructural control is possible even under extreme thermal gradients. By shifting the grain morphology from coarse dendritic to fine equiaxed structures, the propensity for hot tearing is drastically reduced. This achievement does more than just improve quality; it unlocks the ability to manufacture thin-walled, lightweight components that were previously believed un-castable, directly contributing to vehicle weight reduction and fuel efficiency.

However, the technical success of SHSB-TiC technology is only one pillar of the NetCastPL4.0 legacy. The project has identified that the future of casting is inherently digital. The lack of specialized expertise in the foundry industry cannot be solved by traditional training alone. Instead, the project advocates for a synergy between human intelligence and digital tools. By integrating the metallurgical intelligence into Generative Design and Topology Optimization software, we have created a pathway where the complexity of thin-wall physics is managed by AI-driven algorithms. These tools do not replace the engineers; they empower them. The transition from black-box AI to trusted Digital Twins allows for the simulation of secondary alloy behavior with unprecedented accuracy. This digital thread ensures that the knowledge gained during NetCastPL4.0 is preserved and made accessible to a new generation of designers, effectively bridging the talent gap that currently threatens industrial competitiveness.

Furthermore, NetCastPL4.0 has successfully addressed the Circular Economy mandate, which is now a non-negotiable requirement for European Union funding and industrial survival. The shift toward secondary metallurgy with utilizing recycled scrap, introduces a high degree of chemical uncertainty. Our research has concluded that circularity must not lead to downcycling. By utilizing the advanced grain refinement techniques developed in the NetCastPL4.0 project, it is possible to mitigate the harmful effects of tramp elements and contaminants found in secondary melts. This ensures that recycled aluminum and ferrous alloys can maintain the high structural integrity required for critical components. The project's focus on reducing CO_2 and pollutant emissions aligns perfectly with the EU's decarbonization goals, proving that a low-carbon foundry is technically viable without sacrificing material performance.

Finally, the roadmap to 2030 recognizes that technological brilliance is insufficient without economic scalability. The high costs associated with vacuum-assisted die casting and hybrid inserts have historically prevented their widespread adoption. NetCastPL4.0 project addresses this through a dual-track approach: reducing rejection rates (scrap) through superior process control and establishing a training school that merges technical mastery with business insight. By lowering the cost of quality and providing automated NDT (Non-Destructive Testing) solutions for thin-walled parts, advanced casting economically will be made accessible. This holistic approach proposed via the NetCastPL4.0 schools ensures that the innovations developed here are not just academic curiosities, but can be industrial assets ready for mass production in the near future.

In summary, the NetCastPL4.0 project concludes that the future of the casting industry lies in the seamless integration of advanced inoculation metallurgy, AI-enhanced digital workflows, and rigorous circular economy principles. The move to TRL 7 marks the beginning of a new era where thin-walled and high-performance castings are produced reliably, sustainably, and profitably. This project provides the definitive roadmap for the European foundry industry to lead the global market into 2030 and beyond, ensuring a resilient and carbon-neutral manufacturing landscape.

Annex: Survey and feedback received

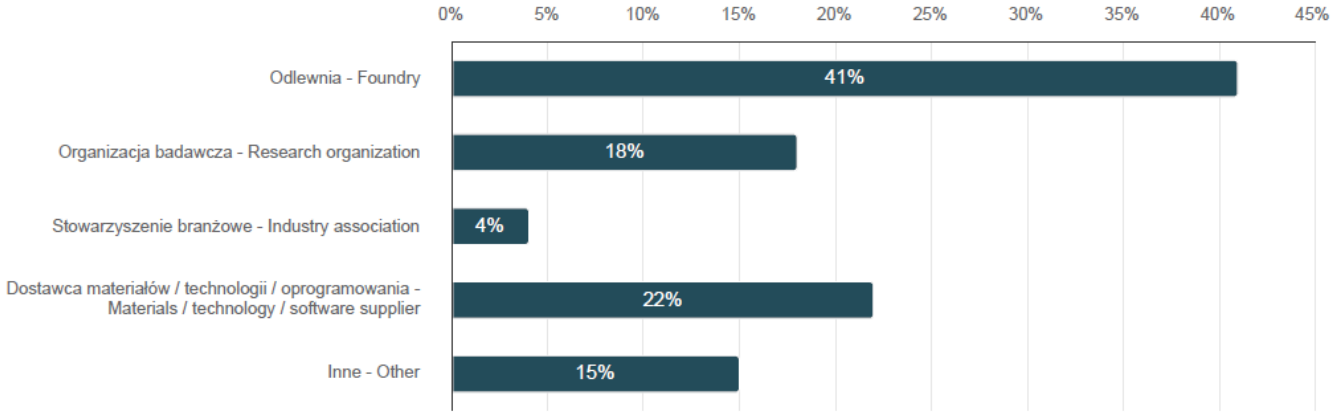
Basic report

Roadmap for Thin-Walled Casting Production

Total number of respondents: 27

Kategoria interesariusza - Stakeholder Category

Number of respondents: 27



	n	Percent
Odlewnia - Foundry	11	40.8%
Organizacja badawcza - Research organization	5	18.5%
Stowarzyszenie branżowe - Industry association	1	3.7%
Dostawca materiałów / technologii / oprogramowania - Materials / technology / software supplier	6	22.2%
Inne - Other	4	14.8%

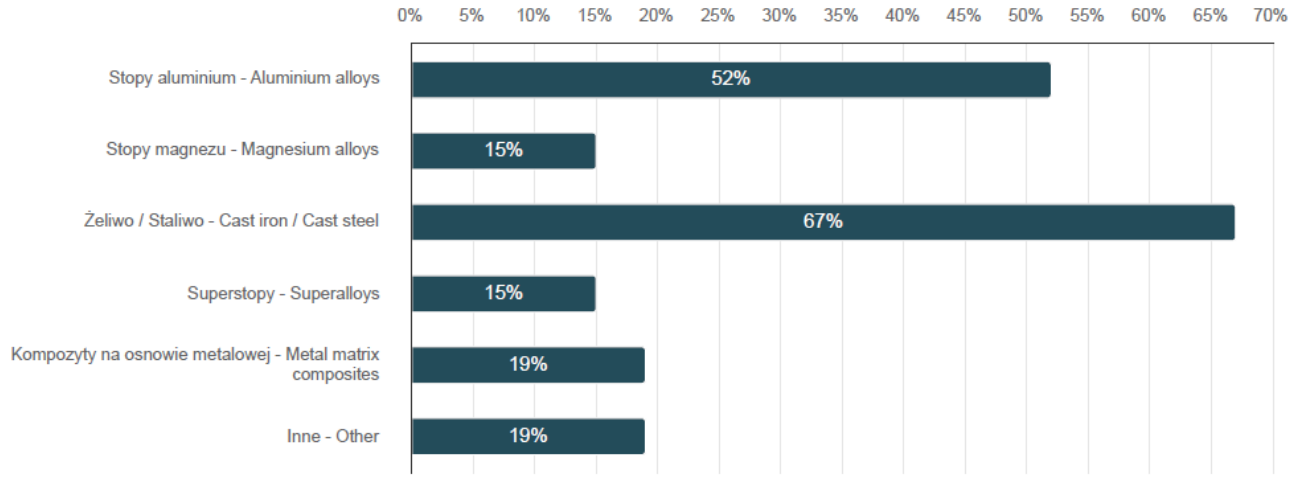
Answers given into textfield

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Option names	Text
Inne - Other	Uczelnia
Inne - Other	R&D
Inne - Other	Association
Inne - Other	Foundry Training organization

Główne materiały wykorzystywane w Państwa działalności - Main materials in your activity

Number of respondents: 27 , selected answers: 50



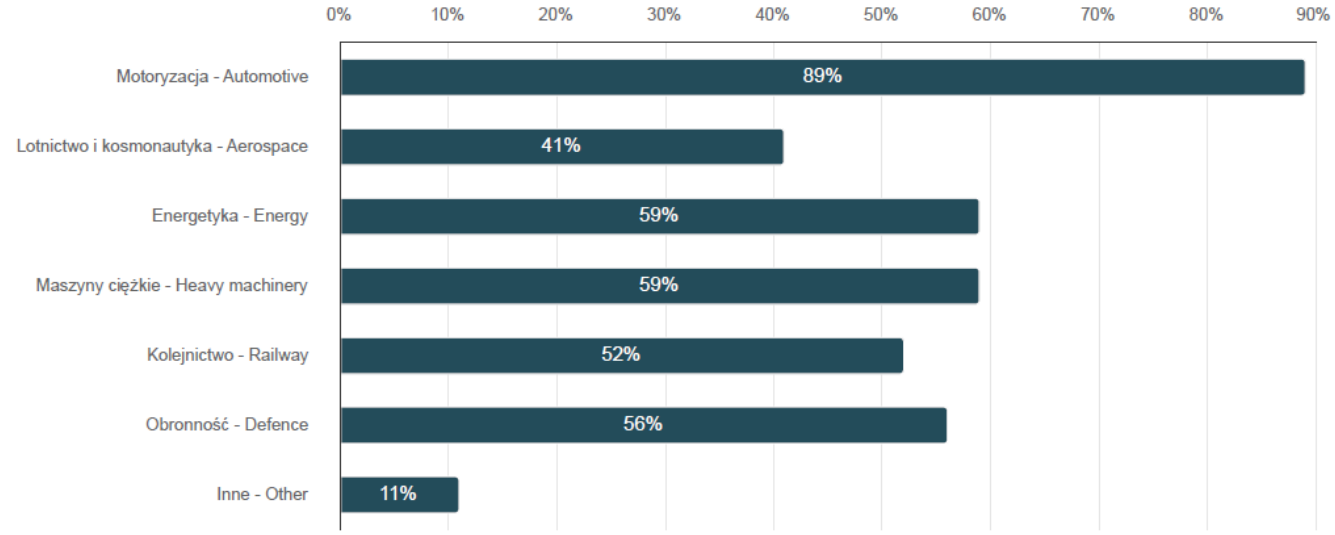
	n	Percent
Stopy aluminium - Aluminium alloys	14	51.9%
Stopy magnezu - Magnesium alloys	4	14.8%
Żeliwo / Staliwo - Cast iron / Cast steel	18	66.7%
Superstopy - Superalloys	4	14.8%
Kompozyty na osnowie metalowej - Metal matrix composites	5	18.5%
Inne - Other	5	18.5%

Answers given into textfield
Show all

Option names	Text
Inne - Other	Papier
Inne - Other	materiały formierskie
Inne - Other	stopy miedzi
Inne - Other	stopy miedzi
Inne - Other	Molding materials

Główne branże docelowe - Key application sectors

Number of respondents: 27 , selected answers: 99



	n	Percent
Motoryzacja - Automotive	24	88.9%
Lotnictwo i kosmonautyka - Aerospace	11	40.7%
Energetyka - Energy	16	59.3%
Maszyny ciężkie - Heavy machinery	16	59.3%
Kolejnictwo - Railway	14	51.9%
Obronność - Defence	15	55.6%
Inne - Other	3	11.1%

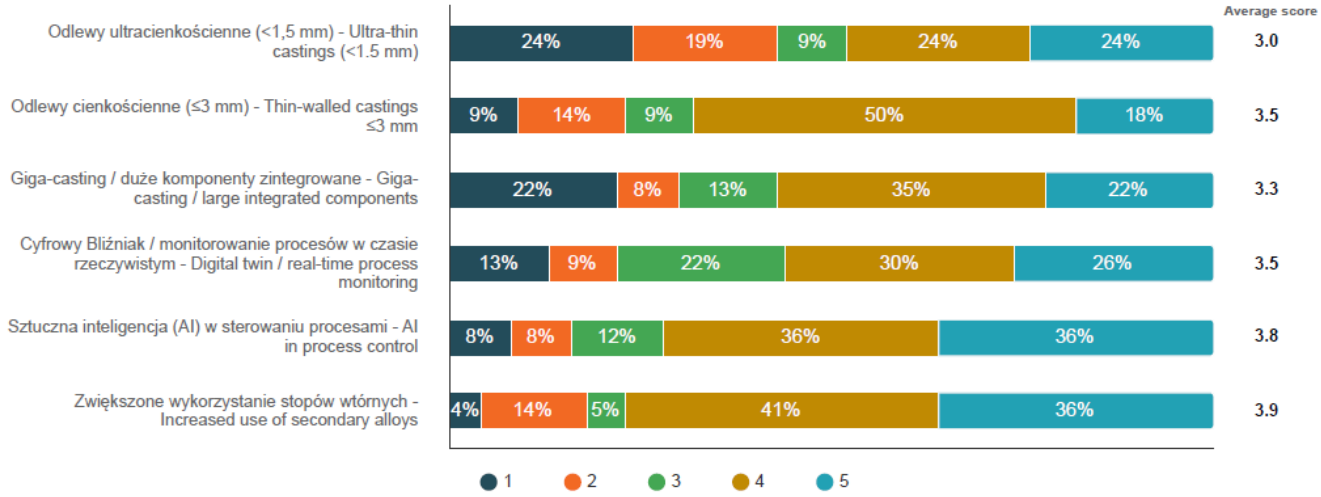
Answers given into textfield

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Option names	Text
Inne - Other	Rolnictwo
Inne - Other	Sprzęt gospodarstwa domowego, elektronika
Inne - Other	Architecture

Jak istotne dla Państwa strategii do roku 2030 są poniższe trendy? (1 = Nieistotne, 5 = Najwyższy priorytet) - How critical are the following trends for your 2030 strategy? (1 = Not relevant, 5 = Absolute priority)

Number of respondents: 26



	1	2	3	4	5	Average	Median
Odlewy ultracienkościenne (<1,5 mm) - Ultra-thin castings (<1.5 mm)	23.8%	19.1%	9.5%	23.8%	23.8%	3.0	3.0
Odlewy cienkościenne (≤3 mm) - Thin-walled castings ≤3 mm	9.1%	13.6%	9.1%	50.0%	18.2%	3.5	4.0
Giga-casting / duże komponenty zintegrowane - Giga-casting / large integrated components	21.7%	8.7%	13.1%	34.8%	21.7%	3.3	4.0
Cyfrowy Bliźniak / monitorowanie procesów w czasie rzeczywistym - Digital twin / real-time process monitoring	13.1%	8.7%	21.7%	30.4%	26.1%	3.5	4.0
Sztuczna inteligencja (AI) w sterowaniu procesami - AI in process control	8.0%	8.0%	12.0%	36.0%	36.0%	3.8	4.0
Zwiększone wykorzystanie stopów wtórnych - Increased use of secondary alloys	4.6%	13.6%	4.5%	40.9%	36.4%	3.9	4.0
Total	**13.4%**	**12.0%**	**11.7%**	**36.0%**	**27.0%**	3.5	**4.0**

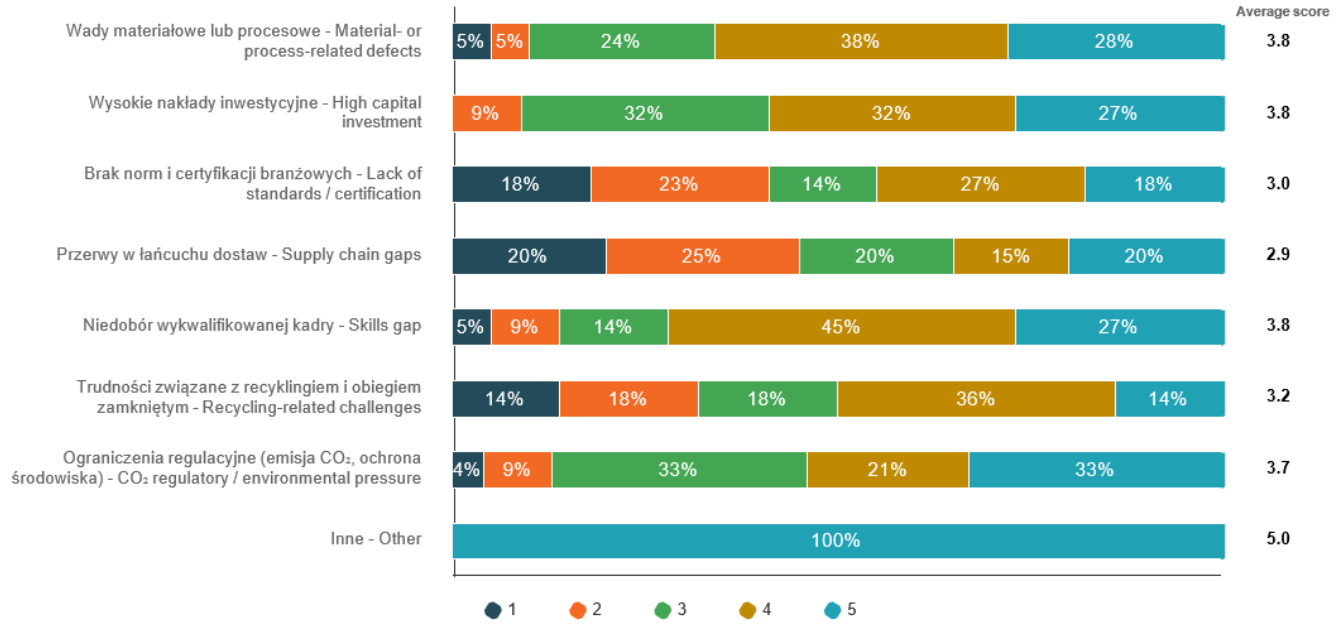
Krótki komentarz (Pytaniu 5) - Short comment (Question 5)

Number of respondents: 19

Responses
Development of casting technologies.
A particularly important area of the company's activity is the production of thin-walled castings made of aluminium-based composites, including a high share of secondary alloys (secondary ingots). In the automotive sector, weight reduction through decreasing wall thickness remains a key development direction. An additional important research task is the recovery of tungsten from recycled worn cutting inserts, used in anti-wear solutions. Across all areas, the implementation of artificial intelligence for real-time data prediction and analysis is also essential, supporting process optimisation and increasing efficiency.
The production of thin-walled castings has a significant impact on the weight of final products. Considering that one of the main markets for castings is the automotive industry, the weight aspect is of major importance. Furthermore, the implementation of digital transformation substantially facilitates the production process.
The current production profile does not foresee the manufacturing of thin-walled castings in the near future.
In the near future, the primary challenge will be extremely thin-walled "double wall" castings, i.e. blade castings with dual walls.
An engineering and technology company without its own casting production profile.
The main objectives are to establish a technological and production base for large aluminium castings using gravity die casting as well as low-pressure casting. Additionally, real-time process monitoring and data acquisition constitute a pro-quality element and indicate potential directions for technological improvements.
N/A
AI is slop, while digital twin approach is a methodology which are easy to be emptied in modern industry using current IT and automation technologies.
The foundry specialises exclusively in serial production of iron castings weighing up to 30 kg.
Large integrated components and thin wall castings are objectives of the same innovation in metal product development. The challenge to produce such new components can find solutions and benefits from Digital twin and AI in process control.
Development of technologies and raw material resources.
The above results from the automotive market demand for lighter castings, combined with effective management within a circular economy framework.
In our case, casting is part of a broader activity scope related to metallurgy and metal processing.
For our company (high-pressure die casting of aluminium alloys) and based on customer forecasts up to 2030, we anticipate a significant share of thin-walled castings with wall thicknesses around 3 mm.
Key factors will include process digitalisation, real-time monitoring, and increased use of secondary raw materials—driven by cost, quality, and environmental pressures. Trends such as giga-casting or ultra-thin walls are of lesser importance in the context of iron casting production.
Ultra-thin-walled castings (<1.5 mm). High potential in sectors requiring weight reduction (automotive, e-mobility, electronics). However, they require advanced process and quality control; therefore, their development will be selective but strategically important. Thin-walled castings (≤3 mm). An absolute priority in terms of lightweight design, energy efficiency, and material optimisation. A widely applicable trend and technologically closer to large-scale implementation than ultra-thin walls. Giga-casting / large integrated components. A highly important direction, especially in the automotive sector, due to functional integration and reduction in the number of parts. However, it requires substantial investment and appropriate production scale. Digital Twin / real-time process monitoring. A key element of transformation towards Industry 4.0. It directly impacts quality stability, scrap reduction, and cost optimisation, forming the foundation for further automation and production scaling. Artificial intelligence (AI) in process control. A natural extension of digital monitoring—enabling predictive control, self-learning process models, and minimisation of deviations. By 2030, it is expected to be one of the main sources of competitive advantage. Increased use of secondary alloys. A strategic priority in the context of decarbonisation, ESG requirements, and the circular economy. Critical from both cost and regulatory perspectives, with a strong long-term impact on the entire sector.
Due to the shrinking availability of primary raw materials, the utilisation of scrap feedstock becomes essential.
We are observing particular interest in issues related to the use of secondary alloys, especially aluminum alloys.

Jak istotne są poniższe ograniczenia dla rozwoju technologii odlewów cienkościennych w Państwa organizacji? (1 = Ograniczenie nieistotne, 5 = Ograniczenie krytyczne) - How significant are the following barriers to the development of thin-walled casting technologies in your company? (1 = Negligible barrier, 5 = Critical barrier)

Number of respondents: 25



	1	2	3	4	5	Average	Median
Wady materiałowe lub procesowe - Material- or process-related defects	4.7%	4.8%	23.8%	38.1%	28.6%	3.8	4.0
Wysokie nakłady inwestycyjne - High capital investment	0.0%	9.1%	31.8%	31.8%	27.3%	3.8	4.0
Brak norm i certyfikacji branżowych - Lack of standards / certification	18.2%	22.7%	13.6%	27.3%	18.2%	3.0	3.0
Przerwy w łańcuchu dostaw - Supply chain gaps	20.0%	25.0%	20.0%	15.0%	20.0%	2.9	3.0
Niedobór wykwalifikowanej kadry - Skills gap	4.5%	9.1%	13.6%	45.5%	27.3%	3.8	4.0
Trudności związane z recyklingiem i obiegiem zamkniętym - Recycling-related challenges	13.6%	18.2%	18.2%	36.4%	13.6%	3.2	3.5
Ograniczenia regulacyjne (emisja CO_2, ochrona środowiska) - CO_2 regulatory / environmental pressure	4.2%	8.3%	33.3%	20.9%	33.3%	3.7	4.0
Inne - Other	0.0%	0.0%	0.0%	0.0%	100.0%	5.0	5.0
Total	**8.2%**	**12.2%**	**19.3%**	**26.9%**	**33.5%**	**3.5**	**4.0**

Answers given into textfield

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Option names	Text
Inne - Other	automatisation
Inne - Other	Energy costs and access to raw materials

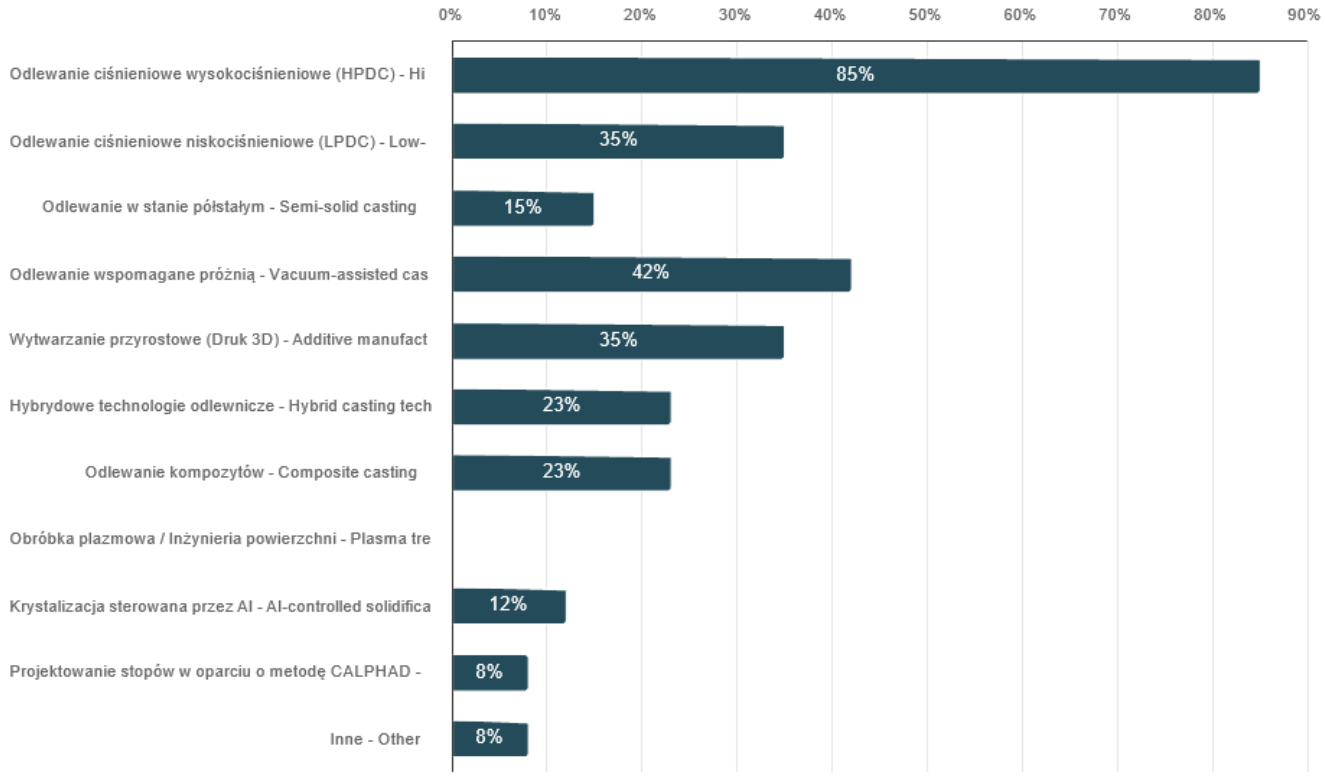
Szczegóły techniczne (Pytaniu 7) - Technical details (Question 7)

Number of respondents: 14

Responses
The current production profile does not foresee the manufacturing of thin-walled castings in the near future.
Our main challenges are primarily focused on improving metallurgical yield and, consequently, reducing the number of defects. Another challenge is the reduction of production costs, particularly through process automation.
The most critical issue is the limited availability of qualified personnel, as well as the costs associated with implementing technologies enabling the production of thin-walled castings.
Not applicable.
Environmental initiatives unfortunately do not support industrial development.
Supply chain and skills are fundamental to invest resources in characterization, certification and demonstrate the solution for recycling and environmental challenges.
Development of technology and raw material resources.
Major UK issues Skills and energy.
Due to the use of bentonite-bonded moulding sands.
Thin-walled casting is not a leading topic in our organization.
Process instabilities at high injection speeds, increased porosity, and a narrow process window are key issues. Limitations also include high costs of both casting tooling and equipment required to stabilize high-pressure die casting processes. Additional barriers include high energy costs and environmental requirements.
-
The most critical barriers are technological (process stability and metallurgical quality) and competence-related. Financial and regulatory barriers are also significant, but can be mitigated through production scale, digitalization, and the development of engineering competencies.
Not applicable.

Które technologie mają największy potencjał w produkcji odlewów cienkościennych? - Which technologies have the greatest potential for thin-walled casting production?

Number of respondents: 26 , selected answers: 74



	n	Percent
Odlewanie ciśnieniowe wysokociśnieniowe (HPDC) - High-Pressure Die Casting (HPDC)	22	84.6%
Odlewanie ciśnieniowe niskociśnieniowe (LPDC) - Low-Pressure Die Casting (LPDC)	9	34.6%
Odlewanie w stanie półstałym - Semi-solid casting	4	15.4%
Odlewanie wspomagane próżnią - Vacuum-assisted casting	11	42.3%
Wytwarzanie przyrostowe (Druk 3D) - Additive manufacturing (3D printing)	9	34.6%
Hybrydowe technologie odlewnicze - Hybrid casting technologies	6	23.1%
Odlewanie kompozytów - Composite casting	6	23.1%
Obróbka plazmowa / Inżynieria powierzchni - Plasma treatment / surface engineering	0	0.0%
Krystalizacja sterowana przez AI - AI-controlled solidification	3	11.5%
Projektowanie stopów w oparciu o metodę CALPHAD - Alloy design based on CALPHAD	2	7.7%
Inne - Other	2	7.7%

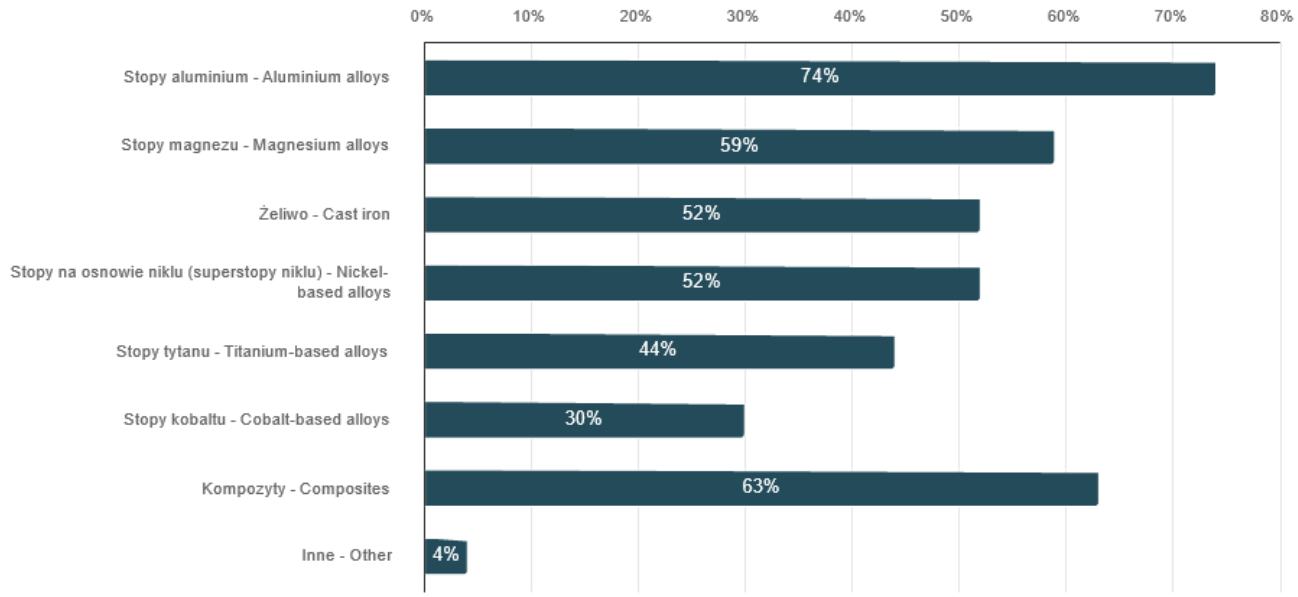
Answers given into textfield

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Option names	Text
Inne - Other	N/A
Inne - Other	digital twin of monitored production processes

Które kierunki materiałowe będą kluczowe do roku 2035? - Which material directions will be key by 2035?

Number of respondents: 27 , selected answers: 102



	n	Percent
Stopy aluminium - Aluminium alloys	20	74.1%
Stopy magnezu - Magnesium alloys	16	59.3%
Żeliwo - Cast iron	14	51.9%
Stopy na osnowie niklu (superstopy niklu) - Nickel-based alloys	14	51.9%
Stopy tytanu - Titanium-based alloys	12	44.4%
Stopy kobaltu - Cobalt-based alloys	8	29.6%
Kompozyty - Composites	17	63.0%
Inne - Other	1	3.7%

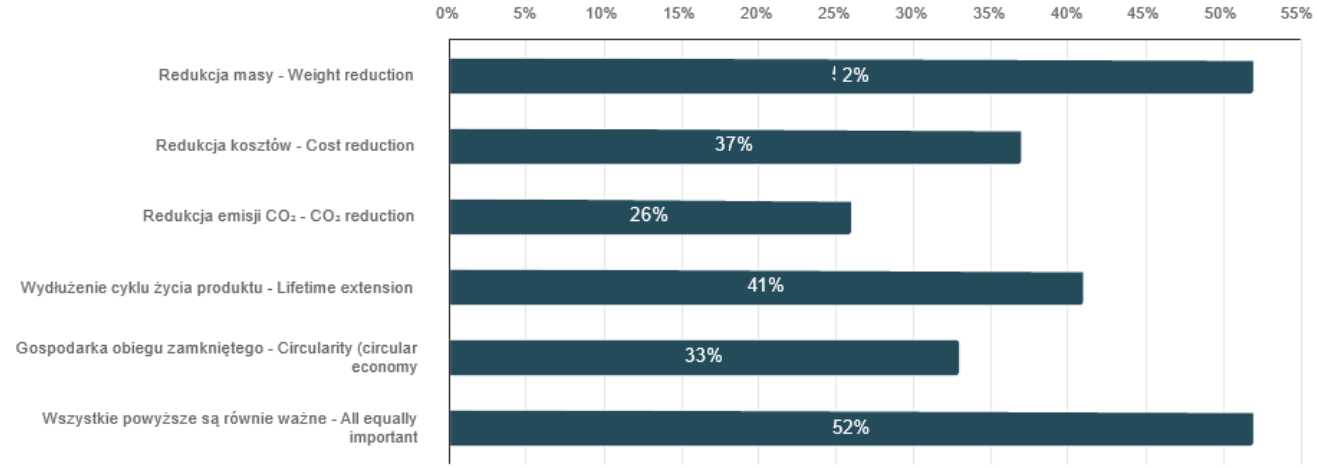
Answers given into textfield

Show all

Option names	Text
Inne - Other	All have its applications, either in broad and/or local scope

Co powinno być głównym czynnikiem stymulującym produkcję odlewów cienkościennych? - What should be the main driving factor in thin-walled casting production?

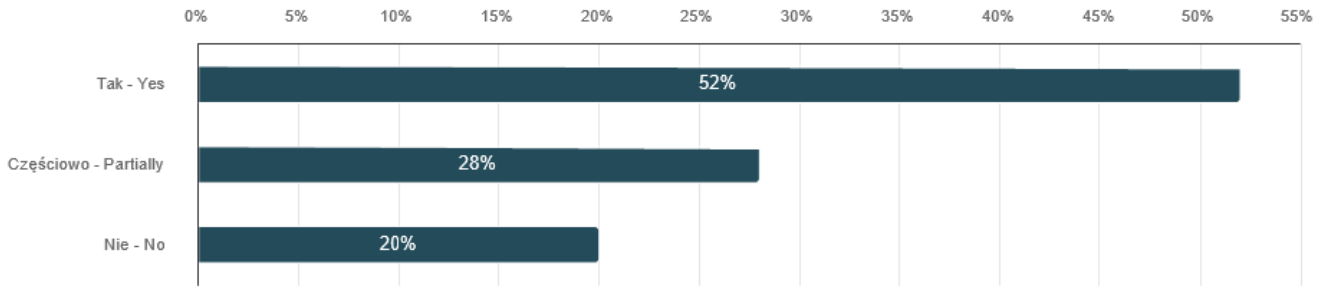
Number of respondents: 27 , selected answers: 65



	n	Percent
Redukcja masy - Weight reduction	14	51.9%
Redukcja kosztów - Cost reduction	10	37.0%
Redukcja emisji CO_2 - CO_2 reduction	7	25.9%
Wydłużenie cyklu życia produktu - Lifetime extension	11	40.7%
Gospodarka obiegu zamkniętego - Circularity (circular economy	9	33.3%
Wszystkie powyższe są równie ważne - All equally important	14	51.9%

Czy wykorzystują Państwo surowce wtórne w ilości przekraczającej 30% udziału? - Do you use secondary raw materials at a share >30%?

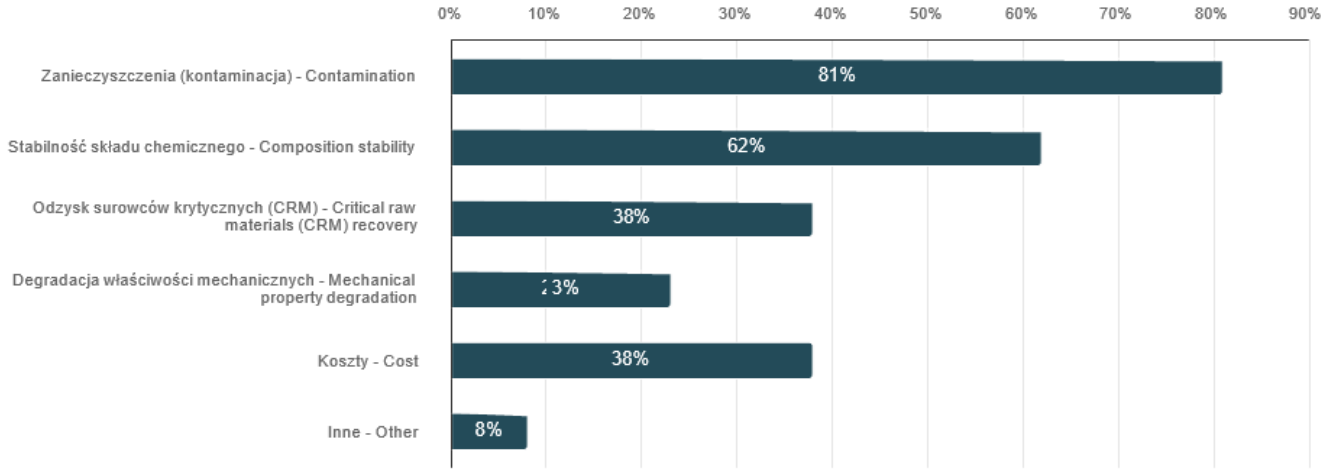
Number of respondents: 25



	n	Percent
Tak - Yes	13	52.0%
Częściowo - Partially	7	28.0%
Nie - No	5	20.0%

Największe wyzwania w recyklingu odlewów lekkich - Biggest challenges in recycling lightweight castings

Number of respondents: 26 , selected answers: 65



	n	Percent
Zanieczyszczenia (kontaminacja) - Contamination	21	80.8%
Stabilność składu chemicznego - Composition stability	16	61.5%
Odzysk surowców krytycznych (CRM) - Critical raw materials (CRM) recovery	10	38.5%
Degradacja właściwości mechanicznych - Mechanical property degradation	6	23.1%
Koszty - Cost	10	38.5%
Inne - Other	2	7.7%

Answers given into textfield

Show all

Option names	Text
Inne - Other	All above

Jakie nowe technologie / materiały mogą zostać wdrożone w Państwa firmie w ciągu najbliższych 5 lat? Jaki jest obecny Poziom Gotowości Technologicznej (TRL) technologii wymienionych? - What new technologies / materials in your company could be implemented within the next 5 years? What is the current Technology Readiness Level (TRL) of the technologies mentioned?

Number of respondents: 17

Responses
Technology for producing composite wear-resistant layers using liquid reactive casting coatings – applications include the mining industry and brake discs. TRL 7–8. Development of Al–Si–nanoTiC composites intended for the production of aluminum wheels (alloy rims) and large components such as gigacastings. TRL 3–4.
Due to the operational profile of the Polish Foundry Chamber of Commerce, it is difficult to provide a clear answer to this question.
TRL 9
We do not plan to introduce new technologies, except for the automation and robotization of current manual operations. Currently, the level of automation is estimated at TRL 5–6.
x
Technologies that are fully industrialized and implemented are currently the standard, carried out under foundry production conditions.
x
I represent a university, therefore the TRL range is 3–8.
Production of compacted graphite iron (CGI) castings. Production start is planned for 2027. The foundry is at the stage of patent acquisition and preparing a funding application. TRL 3–4 / TRL 5–6
Modification of casting properties in selected surface regions. Laser repair of casting defects. Regeneration of metal molds and cores. TRL 8
TRL 3-4 lots of issues
ADI - TRL 3 - 4
We primarily conduct research and development across a broad spectrum of metallurgy and metal processing, covering TRL levels 1–9.
The highest potential within the next 5 years is seen in:thin-walled HPDC/LPDC,Al-based process control,alloy optimization using CALPHAD,increased use of secondary alloys. Additive technologies and vacuum-assisted processes will be used mainly for prototyping or low-volume production. TRL analysis shows that some solutions are close to industrial implementation, while others require further testing and validation.
Additive technologies (sand printing) – TRL 5–6. Ferritic–austenitic cast iron produced without heat treatment – TRL 3–4
Removal of iron from Al alloys by filtration (TRL 6). Recycling of particle-reinforced cast composites (TRL 4) Use of emission-free heat sources in melting Al alloys (TRL 7) Use of emission-free heat sources in the heat treatment of Al (TRL 4) Use of plasma in the recycling of Al and copper alloys (TRL 3)
TRI5-6