DOI: 10.24425/academiaPAS.2024.152349

# Casting

# THE FUTURE


SYLWIA PIWOWAR

**Prof. Natalia Sobczak,** Vice President of the Polish Academy of Sciences, shares insights into her work as an engineer specializing in liquid metals, highlighting key aspects of her profession.

**What is being a foundry engineer all about?**

NATALIA SOBCZAK: Metalcasting is an ancient craft. For centuries, humans have created different alloys and metal products, which are essential to our civilization. Traditionally, this craftsmanship was based on trial and error, which was both costly and time-consuming. Science now allows us to approach this process with greater precision, reducing both production time and costs. Nowadays foundry engineering is about processing and manufacturing products by harnessing the unique properties of liquid metal. We bring metal to a liquid state, shape it, and add various components – it's a bit like seasoning a soup by adding spices. These additives alter the metal's characteristics, allowing us to achieve the desired properties in the final material and product.

My research focuses on controlling these processes in relation to external environmental factors. We seek optimal ingredients and conditions to create materials with the best possible utility properties. This enables us to produce metal products with high durability, corrosion resistance, or other specific characteristics.

**Where do the main applications of your research lie?**

Our research provides a foundation for theorists across various interdisciplinary fields – from materials engineering to geology and astronomy. The highest-quality materials find applications in industry, across many sectors. One of the major challenges is the growing scarcity of critical raw materials, along with new regulations mandating the elimination of certain elements that have been traditionally used for millennia, but are now recognized (based on research) as toxic and harmful. As a result, we need to develop

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Artistic castings

new alloys or modify the chemical composition of existing ones. This requires changes to production technology or the design of the final product, leading to what we call *comprehensive material-structural-technological conversion*.

**What led you to choose this profession and career path? Was it by happenstance, or has it always been your passion?**

My family placed a strong emphasis on education and personal development. A key person who influenced my choices was my math teacher in high school. I was incredibly fortunate to have met her. She had an exceptional talent for recognizing and nurturing each student's abilities. Thanks to her guidance and support, I studied in two schools at once – with my peers and additionally in a specialized school focused on physics and mathematics. That's when I realized the sciences were my passion. At first, I wanted to study nuclear physics, which was popular at the time, but my father convinced me to change my focus. My hometown had many metallurgical plants, so studying in the physics-metallurgy department was a natural choice. This decision ultimately turned out to really be on-target.

**Did you go straight into doctoral studies after graduation?**

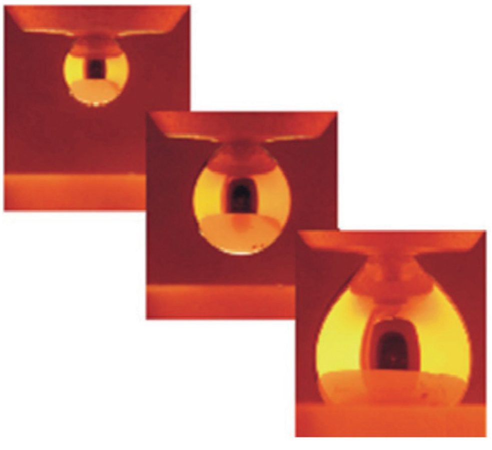
It was more a dream of mine, as getting into doctoral studies wasn't easy back then. As an undergraduate, I started pursuing a career in science by joining a student research association and was lucky enough to work on projects led by outstanding scientists. That experience ultimately convinced me I'd made the right choice. The path I took taught me humility and patience, which turned out to be invaluable in both life and work.

**How did your research work progress from there?**

After earning my doctorate in 1984, I had hoped to work at the Aleksander Krupkowski Institute of Metallurgy and Materials Science of the Polish Academy of Sciences. Instead, I accepted a temporary position at the Foundry Research Institute in Kraków, offered by the then-director, Prof. Zbigniew Górny. This decision turned out to be pivotal; instead of staying for three months, I ended up working there for nearly 35 years, researching cast metal matrix composite materials – a new field in Poland at the time.

In 1989, I secured the Institute's first international project through the UNIDO program. This was a major milestone, as we had no prior experience with international grant applications. The funding allowed us to train over 20 people domestically with UNIDO experts, with some receiving further training at research centers and industrial sites abroad. This project not only introduced us to advanced research and technology but also enabled us to build our own research team and upgrade our equipment. However, the most valuable outcome was establishing collaborations with world-class scientists, which accelerated the growth of our Composite Materials Team.

Professor Pradeep Rohatgi, head of the Center for Advanced Materials at the University of Wisconsin–Milwaukee and acknowledged by the American Foundry Society as the father of cast composites, proposed a collaboration under the US-Poland Joint Fund (supported by the US National Institute of Standards and Technology – NIST). The project aimed to study the thermophysical properties of liquid aluminum alloys using our equipment. Over the following years, this partnership led to research fellowships in the US under Prof. Rohatgi for both my husband and me, allowing us to actively participate in the ongoing research there. This collaboration paved the way for further projects, including a three-year NIST-funded project led by my husband, which focused on applying squeeze casting technology in the production of metal matrix composites. This technology uses pressure not only to infiltrate the porous reinforcement with liquid metal but also as a thermodynamic factor that shapes the microstructure of castings.



Liquid metal drop test on a substrate

**You founded the School of Liquid Metal Engineering. Could you tell us how that came about?**

During the UNIDO project, I met Prof. Nicolas Eustathopoulos from the Grenoble Institute of Technology, and together we've been working on improving research methods for testing liquid metals. Professor Eustathopoulos went on to organize the first international conference on high-temperature phenomena in liquid materials, which led to an invitation for me to participate and a proposal to establish the International Committee for High Temperature Capillarity (HTC) alongside leading experts in this field.

The formation of the HTC International Committee and its ongoing conferences have significantly advanced this important area of science worldwide. Today, it's increasingly referred to as Liquid Metal Engineering (LME) and is recognized as a vital research field within materials engineering.

**What were the biggest challenges and successes in organizing the HTC International Committee and its conferences?**

Research into high-temperature phenomena in liquid metals and alloys presents unique challenges because, at high temperatures, everything tends to react with everything else. This requires specialized equipment that isn't commercially available, and there are no established standards. Working within the HTC community allowed us to refine research methods and procedures and to design our own equipment, which has been validated through patents and awards. Our studies have led us to discover and understand fascinating phenomena such as high-temperature *liquiphobia* (non-wetting behavior), the "structural memory" of liquid metal, structural inheritance, the "dancing metal drop" phenomenon, and *whiskering* mechanisms (giving rise to whisker-like structures) on solid surfaces in contact with liquid metal. These findings have applications across a range of industries, from aviation to nuclear energy.

This may come across as immodest, but in fact I'm not aware of any other team worldwide that can match our achievements in creating equipment for liquid metal research. Thanks to this equipment, we have conducted advanced studies on various metals and alloys, and the characteristics we established now serve as reference "material genes" (NIST Materials Genome Initiative; NASA Astrophysics Data System, http://adswww.harvard.edu) for modeling and optimizing liquid-phase processes as well as for AI-related work.

Our philosophy of "seeing the invisible" also allowed us to develop essential guidelines for different high-temperature liquid-assisted processes for joining dissimilar materials such as soldering, brazing, welding, and 3D printing. Today, we conduct this research at the newly established Liquid Metal Engineering Laboratory at the AGH Faculty of Foundry Engineering, in close cooperation with the Institute of Metallurgy and Materials Science, PAS.

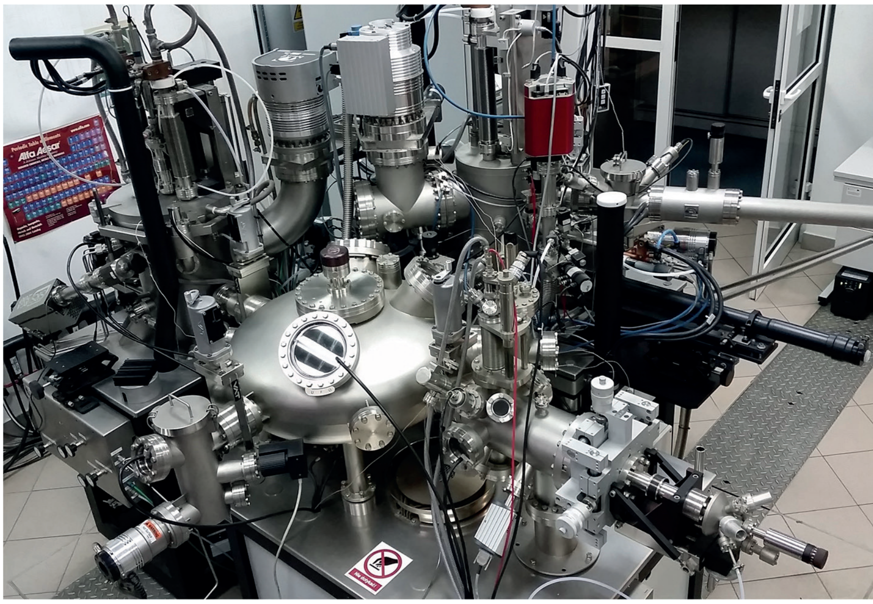
**What was your experience working in the United States?**

Looking back, I'd say that my first trip to the United States and working at an American university were pivotal moments for both my team's development and for my own career. I gained valuable experience and built international contacts that led to further projects, joint publications, and fresh ideas. At first, I was unsure if I'd manage, but once there, I found that the university's whole structure was based on trust, providing each scientist with a creative, supportive environment with minimal bureaucracy. I had complete access to labs, equipment, support materials, libraries, and software – I could work whenever I needed. It was a real culture shock but also, once again, a kind of dream come true.

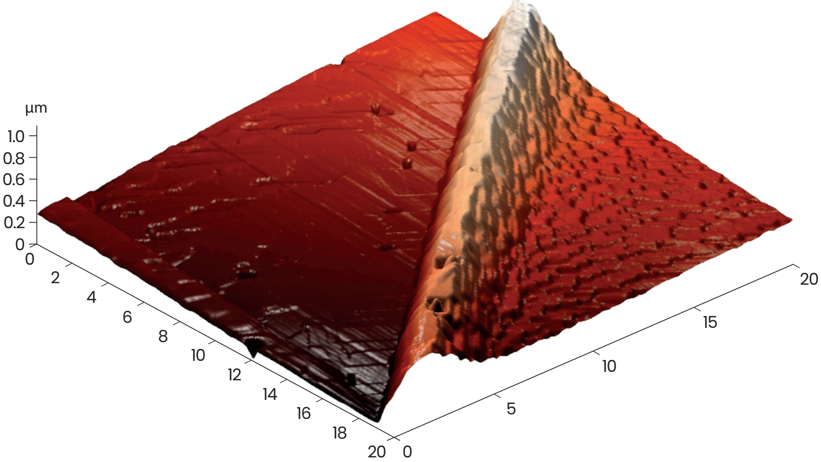
This is why I now strongly encourage young scientists to be mobile – they should go abroad as early as possible, experience top-level science firsthand, and decide if they want to keep growing in that environment.

**You have also worked in Japan. Looking back, how do you remember your time working there?**

The terms of my one-year contract in Japan were quite different from those in the United States. I received a professorship based on my achievements and experience. At my very first meeting with Professor



Laboratory complex for advanced research




Changes in surface topography (the surface ridge phenomenon)

This QR code links to a video illustrating the "dancing drop" phenomenon in real-time, showing the high-temperature interaction of a cast iron drop with zirconium oxide substrates containing various additives: left – yttrium oxide; right – magnesium oxide, https://youtu.be/5-FYDtrW8dE

Kiyosi Nogi, he told me: "Just enjoy your stay here in Japan." My responsibilities included research, consulting, working with PhD students, and lecturing at Japan's leading universities, allowing me to visit many places. I had the opportunity to work independently on high-temperature devices, which helped me learn new research techniques and operate specialized software that significantly shortened data analysis times. This also enabled me to conduct research for national and Polish-US projects, contributing to my DSc (*habilitation*) degree upon returning home.

**Could you explain how research on liquid metals can be applied in the economy?**

In 2007, I established the High-Temperature Liquid Metals and Alloys Research Center at the Foundry Research Institute. Its role proved to be crucial and even groundbreaking. Inspired by global laboratories, I designed an experimental complex for studying metals and alloys at temperatures up to 2000°C, which allowed us to develop new methodologies. Together with the company PREVAC we built a unique device, unmatched worldwide, which won the Polish Ministry of Industry's First Award for "The Polish Product of the Future."

Rather than pursuing traditional patents, we presented our findings at the HTC-2007 conference and in the journal *Materials Science and Engineering*, which quickly led to collaboration proposals from global research and industrial groups. In the following years, collaboration with the company MeasLine resulted in a next-generation mobile apparatus with new research capabilities, which won the Gold Medal at the 2021 ITM Industry Europe Trade Fair in the "Science for the Economy" category.

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Prof. Sobczak together with young researchers at the Institute of Fundamental Technological Research, Polish Academy of Sciences

**Which of your many publications are you most proud of?**

One entitled "The Mystery of Molten Metal," which demonstrates the critical role of fundamental research in developing new materials and technologies. It was awarded Best Paper at the 70th World Foundry Congress in Hangzhou, China, in 2010, receiving an international prize from FOSECO. It was also the first opening plenary paper to be delivered by a Polish researcher at a World Foundry Congress. Later, the same paper was selected by the Foundry Institution of the Chinese Mechanical Engineering Society as one of the best publications in basic research for foundry engineering in the decade from 2004 to 2014.

**Do you see applications for artificial intelligence in your field?**

While working as an editor for a number of scientific journals, including for Springer International Publishing, I noticed a few years ago that certain publications seemed to be suspiciously homogenized, even somewhat lacking in scientific depth. Occasionally, the terminology used was quite different from what we typically encounter in research reports. This raised a valid suspicion that these articles might not have been written by scientists.

After these journals deployed specialized analysis software, it turned out that artificial intelligence had indeed been involved in writing these articles. Some journals now accept AI-assisted articles, and some universities even permit AI to be used for literature reviews in master's or doctoral theses. AI can conduct such reviews without interpreting results, which is particularly useful in patent descriptions that rely solely on test data. But AI will become especially valuable once it can "read" researchers' intentions and integrate insights from our experimental experiences and mental simulations. Currently, however, AI still needs to learn to grasp the broader context and subtle nuances that we scientists perceive and rely on to analyze results based on years of experience, knowledge, and intuition.

Working with AI certainly requires one to be very precise with language; otherwise, misunderstandings are bound to occur. For instance, we once tried to ask an AI engine, in Polish, "What alloys does liquid magnesium wet?" (*Jakie stopy zwilża ciekły magnez*?). After a long pause, it responded with: "You're funny." We quickly realized that its apparent confusion stemmed from the double meaning of the Polish word *stopy*, which it had interpreted as referring to a body-part ("feet") rather than "alloys."

We've also seen AI fail to recognize that the definition of alloys in engineering has shifted significantly over the past century. Today, alloys include not only purely metallic materials but also combinations with non-metallic elements, intermetallic compounds, and even oxides, nitrides, carbides, and gases. Furthermore, contrary to the traditional definition of alloys, melting components is no longer essential to create a suitable alloy; for example, this can now be done through mechanical alloying.

But overall, I see immense potential for artificial intelligence applications. If we'd had access to it 30–40 years ago, the progress in research could have been extraordinary. In my field, AI applications are practical when each stage of the experiment is described in detail. Without precise information, the results may be misleading and far from reality.

**How many experiments does one have to perform to achieve success?**

It all comes down to experience, previous failures, a proper approach to one's own research, and that of colleagues. Just like in medicine, it's essential to continuously read, track, and analyze who did what, who changed something, and who improved even the procedure of measurement. I have many examples where a failure was caused by a minor detail.

When I was working on an American project and conducting part of the research in Japan, a colleague at NASA prepared samples but accidentally used a magnesia crucible instead of a zirconia one, as they look nearly identical. The test results on these samples were incorrect, and their behavior during high-temperature experiments was completely at odds with predictions.

It took a long time to get to the bottom of this anomaly, but by following advanced research procedures, especially with meticulous descriptions of each step in sample preparation and experimentation, we discovered that the crucible's material was the issue. During melting, chemical reactions had occurred between the crucible material and the metal, affecting the results in Japan. Such small, "insignificant" details can sometimes be crucial. This is why one must perform many trials and document each detail meticulously to succeed and understand what impacts on the reliability and accuracy of results.

In reality, the number of tests performed alone doesn't guarantee the quality and credibility of the results. In our research, qualities such as a scientist's creativity, precision, and attention to the smallest details are sometimes more significant – traits that, at this stage, are hard to expect from artificial intelligence.

**What challenges do scientists face in their work?**

Currently, the main challenges are undoubtedly armed conflicts, political turmoil, and underfunding of science, which force researchers to move abroad, change jobs unwillingly, or leave science altogether.

I now work at the Aleksander Krupkowski Institute of Metallurgy and Materials Science of the Polish Academy of Sciences – fulfilling a dream I've had since my youth. But being aware of the severe limitations on research and the challenges that the Academy institutes face due to inadequate funding saddens me. I worry that many young, talented scientists won't withstand this pressure and will either move abroad to pursue science or simply change professions.

I believe it's obvious to everyone that civilization cannot progress without systematic innovation. But how can we convince policymakers that there can be no innovation without fundamental research?

Interview by
**Jolanta Iwańczuk, Daniel Sax**

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**Prof. Natalia Sobczak,
Vice President of the Academy**

studies the scientific, methodological, and practical aspects of high-temperature phenomena in liquid metal engineering. Her work includes developing next-generation materials for energy, energy storage, and the automotive industry, as well as ultra-lightweight materials for medical and space applications, and addressing the challenges of bonding diverse materials. She leads the Department of Metallurgical Processes at the Aleksander Krupkowski Institute of Metallurgy and Materials Science of the Polish Academy of Sciences. She is also a lecturer at the Kraków School of Interdisciplinary PhD Studies and now serves as Vice President of the Polish Academy of Sciences for the 2023–2026 term.

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