Metallurgy is key

Metallurgy has been crucial to the development of China and its economy. Ke Lu, director of the Shenyang National Laboratory for Materials Science, Institute of Metal Research, Chinese Academy of Sciences, talks to *Nature Materials* about the outlook for metallurgy and materials science in China.

Tell us about your scientific background and research interests.

I received my first degree from Nanjing University of Science and Technology in 1985, and then moved to the Institute of Metal Research (IMR) for my Master's degree and PhD, awarded in 1990. My thesis focused on amorphous alloys. There was a three-month gap after graduation until I took up a faculty position at IMR. During this time I attended a workshop in China on nanocrystalline materials — then a new research field — which inspired me to study nanocrystallization of amorphous alloys and led to the first paper on devitrification of amorphous alloys as a synthesis route for nanocrystalline metals. Nanocrystalline metals remain my primary research focus to this day. I subsequently took up a postdoc position at the Max Planck Institute for Metal Research (Stuttgart, Germany), working on nanocrystallization kinetics, and in 1993 I was invited to return to IMR to set up a group for the study of nanostructured metals, where I have remained since.

In 2001 I started an 11-year period as director of the institute with the first few years dominated by administrative duties, leaving little time for research. Fortunately, after these initial years, I managed to create more time for research, which is what truly interests me. In 2001 I also became the founding director of the Shenyang National Laboratory for Materials Science (SYNL), a position I still hold.

What are the areas of focus of IMR?

IMR was set up in 1952 to meet the demands of the metallurgy industry in China, which was — and still is — focused in Shenyang. To this day, applied research is the dominant trend at IMR, as well as providing support for the relevant industries. IMR was also created as a centre for scientific research, and this complemented the more applied aspects of research at the institute. Fundamental research is focused in SYNL, which accounts for approximately one fourth of all researchers at IMR. There is close collaboration between these two sets of researchers however, on appropriate projects. Out of all of the Chinese Academy of Sciences (CAS) institutes, IMR has built some of the strongest ties with industry, even though CAS institutes are mainly associated with fundamental research. I should add that IMR is not limited just to metals research; one of the largest divisions at IMR is the Advanced Carbon Division which works on, to give some examples, carbon nanotubes and graphene for use in batteries.


KE LU

So the Shenyang National Laboratory for Materials Science focuses more on fundamental research. Does this influence how PhD students are educated?

Yes. We like our PhD programmes at SYNL to have a substantial fundamental component, and for students to have strong practical skills, ranging from sample preparation to characterization. This is different to most universities and research centres in China, where only technicians are permitted to operate equipment (microscopes and so on). In particular, once our students have collected their data and are analysing it, we encourage them to consider the science behind it, and to use this as a starting point. A solid grounding in the fundamentals of materials science is thus critical. Indeed, we don't want them to accept as fact the findings published in a paper: they should assess the data for themselves and draw their own conclusions. This approach is not easy, but I believe it leads to a solid educational grounding. It is also only through a firm grasp of basic principles that new scientific questions can be answered

As director of IMR I advocated for the requirement that PhD students publish a certain number of papers to graduate to be scrapped. In my group the expectation is that each PhD student publishes one good, thoughtful paper, making understanding the fundamental science key. This does take time, and students feel pressure to publish more papers, for example, to be able to compete for jobs. Compromising is necessary, but my main emphasis is on quality, and most students recognize that this is what matters.

How are faculty members and research staff assessed?

Quality is critical here also. As director, if I noticed that a researcher was publishing an unusually large number of papers, I would tell them to stop and emphasize to them that it is better to publish a small number of quality papers. In fact, the publication output of SYNL has been flat for a number of years because of this drive towards meaningful papers. Unfortunately, assessment based on quantity of papers remains an important metric in China.

For the annual assessment of divisions in SYNL, I ask division heads for a summary, lasting only a few minutes, of what they have achieved (grants awarded, papers published, highlights and so on), followed by a 45-minute presentation of one good story. It shouldn't be a presentation of a paper; I want to hear how a researcher (or a team) has contributed to understanding an outstanding problem. This assessment method requires more effort and careful thinking than a metrics-based approach. Related to this, one of my first decisions when I became director of IMR was to scrap the bonus system, by which a faculty would receive money for publishing in top-tier journals. This system still exists in many research centres in China, but I do not believe that it is a good practice.

Research funding in China is sometimes tied to number of papers published. Does this put researchers in your centre at a disadvantage?

I don't believe so. Telling a good story requires in-depth understanding and this breeds high-quality research. This is recognized and SYNL regularly publishes in, and contributes to, top-tier journals, even though publishing in such journals is not something we make a requirement, or offer financial incentives for. As such, the standard of our research is of great benefit to securing funding.

What does the future hold for the steel industry in China?

Recent steel production in China has been excessive. This has driven down prices, resulting in the closure of many production lines that produce low-quality materials. Interestingly, this has led to greater interest from industry in how research institutes such as IMR can help them regarding improved manufacturing processes and enhanced product quality. A particular advantage that research centres can offer is an understanding of the fundamental science, establishing new technologies from the bottom up.

China is the number one producer of low-quality steels, and the number one importer of high-quality steels. However, given the heavy investment in infrastructure in China, high-quality steels are needed for projects such as high-speed trains. Likewise, in 2015 the first commercial jet designed and built entirely in China — the Comac C919 — was unveiled. Although China is the number one manufacturer of aluminium globally, this plane contained no aluminium alloys made in China. Likewise, no China-made alloys were used in the engines. The complexity of these alloys makes them difficult to produce and China does not yet have the expertise. However, given the growing size of the domestic market for high-quality alloys, and the increasing cost of importing them, a move towards advanced alloys is inevitable and important for the economy.

Does the current landscape allow for technologies and materials that have been developed in the lab to be transferred to industry?

The transfer of technology from lab to industry is always difficult. While the government certainly encourages it, in China there are some additional problems. The protection of intellectual property in China is difficult, and it is not uncommon for one company to copy the technology of another. There also needs to be appropriate financial incentives for a researcher to look towards commercial development. Last, industry and investors in China expect a new technology to turn a profit more quickly than in other countries, typically within a couple of years. This is a cultural issue and is inherent to industry in China. Resultantly, the development of a new technology may be stunted, while many promising early-stage demonstrations remain in the lab.

Are there specific conditions that make China a good place for metals research?

A particular strength is that there is a massive domestic market for metals, which are required for continued infrastructure development and manufacturing in China. As such, there are large demands placed on metallurgy and the amount of available funding reflects this. Also, while many countries struggle to recruit students into science and engineering, these subjects are seen as attractive to young people in China, who value hard skill sets, and see metallurgy and materials science as being interesting subjects, as well as offering reliable and well-paid employment. A large number of students is also a particular strength for lab-based metallurgy as it often requires substantial experimental work.

While China is certainly a good place for metals research, the quality and standard of research output does not match the heavy investment received. This is gradually improving but there is a long way to go. In particular, originality of research is not so strong, and many works might be viewed as follow-up or improvement studies. A possible reason for this is the pressure to publish papers more frequently, reducing time for truly novel research (which is often seen as high risk). Working on industry-based projects can likewise have a negative effect: industry is typically looking for a certain level of understanding to solve a problem, which doesn't require in-depth knowledge of the basic science. Top-level research institutes and universities could do more to encourage original research rather than incremental studies.

For metallurgy, and materials science in general, to continue to flourish in China does anything need to change?

I have some concerns regarding how metallurgy is taught at universities. Perhaps as a result of our education system being based on that in the Soviet Union, we teach in a 'block-by-block' approach, whereby one unit (for example, casting, welding, heat treatment, phase diagrams, mechanical properties and so on) is taught independent of another. However, many problems in materials science require understanding of multiple phenomena, over many length scales. Thus, complex problems can only be solved by having a broad overview, and cannot be solved based on a single 'block'. Linking electronic structure to processing is one example. This approach has been in use for many decades and I have not seen much improvement since I was a student. It should be said that this is a problem intrinsic to a subject such as materials science — which requires understanding of multiple areas of the physical sciences — and many countries encounter this issue.

Another concern is that materials researchers in China do not interact extensively enough with the international community. For instance, evaluation of research proposals seldom involves peers from abroad, and committee panels for honours or awards usually consist entirely of Chinese scientists. Many faculty-level staff are also reluctant to travel internationally for conferences, visit foreign universities, participate in academic exchanges and so on as they do not see direct benefit from these. Instead, they believe that career development and obtaining research funding are best achieved by having extensive contacts and collaborators within China. In the interest of performing good science however, extensive interaction with the international community is critical and can lead to intensive and productive collaboration. I know that my own research continues to benefit from discussion and collaboration with researchers from all over the world.

Last, the main approach for improving properties of metals is alloying. However, a point is often reached where adding elements has limited effect and makes the material less sustainable (that is, more costly, harder to process, difficult to recycle and so on). I believe that a healthier approach is to drive metals development based on less alloying, that is, using less elements, minimizing usage of expensive, scarce or toxic elements, and then looking for ways in which their defect populations and structure might be tuned to optimize performance.

What is your outlook for metallurgy in China?

I am very optimistic. Given the size of China, and the development and growth it is continuing to experience, metallurgy is crucial and this is unlikely to change. Of course, substantial challenges and barriers remain, such as those discussed here: some reform of education is needed and more should be done to encourage original research. Chinese researchers have vision, but enabling steps are needed to realize these ambitions.

INTERVIEW BY JOHN PLUMMER