Creating a Circular Economy for Sustainable Metal Manufacturing

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Scientia

CREATING A CIRCULAR ECONOMY FOR SUSTAINABLE METAL MANUFACTURING

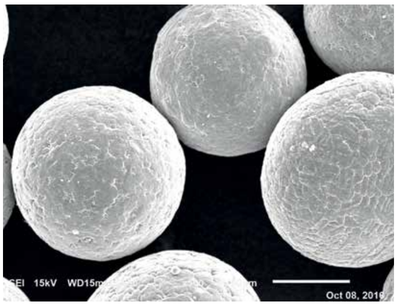
Facilities for recycling metal parts at the locations they are required would be a major milestone in the global struggle towards sustainable industry. Yet for all its advantages, the innovations required to realise such a goal are a daunting prospect. Now, **Andrew LaTour** and his colleagues at MolyWorks Materials are bringing the idea one step closer to reality, through the development of their 'Mobile Foundry'. The company's work could soon provide a new basis for developing a completely closed-loop economy in areas related to metal manufacturing, potentially slashing the industry's negative environmental impacts.

Metal Recycling

Recently, research into manufacturing techniques has revealed significant advantages of converting metal parts into fine powders when they are scrapped. From these powders, new metal parts can be manufactured from scratch through the use of 3D printers, bypassing the need for purchasing new parts. Ultimately, this could create a closed-loop life cycle for such parts, avoiding the necessity for further materials to be extracted from the Earth. Such a system would not only save money, but would also reduce the ecological destruction and emissions associated with mining.

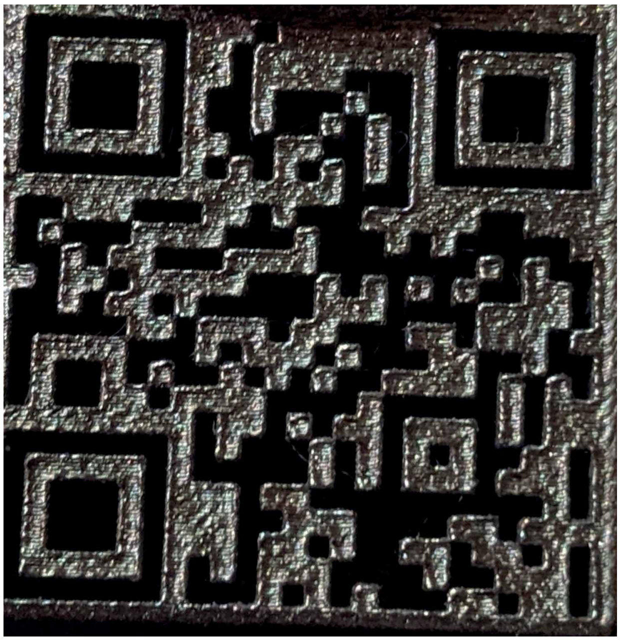
One of the most basic principles of economics is known as 'economies of scale' – the idea that any upscaling in the production of a product will directly correspond to lower production costs. The principle means that in order for such a recycling system to be lucrative, vast amounts of materials need to be manufactured in just a few major, centralised facilities, before being shipped locally. In this case, bulk metals would be gathered by recycling facilities, and then shipped to centralised powder producers. Afterwards, they would be 3D printed into new parts before being shipped back to the original depot.

Despite the economic track record of this system, Andrew LaTour and his colleagues at MolyWorks Materials believe that it has major shortcomings: the shipping of materials over large distances incurs high fuel costs, requires time-consuming logistics, and the emissions significantly contribute to climate change. Metal powders in particular are extremely heavy, which exacerbates the problem further. Because of these deep-rooted issues, the team at MolyWorks now envisages an overhaul of the techniques used to recycle metals worldwide.



Advantages of Distributed Recycling

As mining operations wind down worldwide, incentives are growing for manufacturers to develop smaller, more distributed facilities for producing metal powders. In a recent manuscript, LaTour acknowledges numerous advantages of such systems. He proposes that if metal parts can be scrapped, turned into powder, and 3D printed all at the same depot, huge amounts of wasted energy consumption could be removed from the equation, and tedious shipping regulations could be avoided.



Proof-of-concept testing revealed that where comparable operations in today's economy typically take weeks to months to complete, they could be finished in just days to weeks in an overhauled system – slashing wasted time by up to 90%. In addition, the amount of materials and fuel consumed during the procedure could be reduced by as much as 95%. If realised, such a system would very clearly be far more economically viable and environmentally friendly than current processes. To achieve it, however, LaTour identifies several barriers that must first be overcome.

Difficulties with Melting and Atomisation

To convert bulky metals into powders, two overall steps are required. First, they must be melted; and then, blasted into sprays of fine particles in a process named 'atomisation'. Techniques for melting metals have improved significantly in recent years. In the past, it was done inside crucibles coated with materials such as graphite or ceramic to prevent contamination by impurities. However, these coatings are consumed during melting, which makes the process unsustainable and unable to melt metals at the high speeds required for industrial applications.

The more modern 'plasma cold hearth', constructed using highly conductive materials such as copper, can heat up plasma to temperatures as high as 24,000 degrees, inducing far higher melt rates in the metals exposed to the plasma. However, graphite and ceramics still cannot be completely avoided in these devices, and the melting chambers must be physically entered for cleaning, risking the safety of the operators.

Many other factors must also be optimised, including the ideal gas-to-metal ratio, which affects the sizes of powder particles, gas pressure, metal pour rates, and the type of alloy used – all of which raise the complexity of the problem further.

The Mobile Foundry

To address each of these issues, LaTour and his team at MolyWorks recently developed the Mobile Foundry. This device is capable of melting and atomising metals safely and efficiently, and at the exact locations where their powders are needed. To process metals, the device uses a specialised technique for plasma cold hearth heating, followed by atomisation using a high-pressure stream of argon gas to produce a powder composed of mostly spherical particles.

The Mobile Foundry can work with 16 different metal alloys, including titanium, steel, stainless steel, nickel, aluminium, and copper. In the most recent demonstrations of the device's capabilities, LaTour and his colleagues have shown that it can rapidly process metals as large as 15 centimetres in all three dimensions, without the need for any ceramics or graphite, while still minimising the risk of contamination.

Furthermore, the orientation and shape of the atomisation chamber make it is less confined for those needing to enter it, making the device far easier and safer to clean.

Plasma-arc Melting

The first upgraded element of the Mobile Foundry was the 'transferred-arc' plasma cold hearth melting system. Typically used to weld metals, plasma arc devices operate by forming powerful arcs of electricity between an electrode, and the metal object being worked on – transferring large amounts of heat in the process. High-temperature plasma is then created as gaseous atoms in the path of the arc are broken down into their constituent nuclei and electrons.

By passing an arc through unreactive gas such as argon, LaTour's team has found that they can easily produce plasma free from any impurities, allowing for highly efficient melting when it comes into contact with metal. They also found that as the metal liquefies, it can be refined through separation into elements with different densities – allowing unwanted, lower-density elements to evaporate away. Since this technique achieves fast melting with relatively little effort, the process can become far more environmentally friendly and economically sustainable than previous crucible-based methods.

Atomising the Stream

Next, LaTour and his colleagues developed a system for 'horizontal free-fall' atomisation, in which a falling stream of molten metal meets a fast, horizontal flow of atomising gas. To do this, they used 3D printing to create a series of intricate nozzles. When gas is passed through them, the nozzles create complex vacuum structures that direct metal streams into the regions where they can be broken up by the horizontal gas flow.

Having demonstrated atomisation for a variety of alloys, the researchers then explored the ways in which the process unfolds by capturing it on a high-speed camera. By capturing as many as 60,000 frames per second, the camera allowed the team to identify the exact mechanisms that cause the stream to thin out and break up, giving rise to diverse particle morphologies in the final powder product. It also enabled them to differentiate between the particles produced in different parts of the stream, whose velocity continually changes as it falls.

At the lower end, where the metal had accelerated to higher speeds, LaTour and his colleagues observed that the atomising gas breaks it up into smaller particles, due to physical processes including 'plume-sheet' and 'sheet-thinning' modes, inducing secondary atomisation. Conversely, larger particles were formed in the lower velocity upper regions of the stream, where 'bag' and 'bag-plume' modes were the more dominant physical mechanisms.

Studying Shapes and Sizes

To analyse the morphologies of the atomised particles in further detail, the researchers employed a technique called scanning electron microscopy, which produces images of material surfaces using focused beams of electrons. They saw that most particles were generally spherical in shape, often appearing with agglomerations of several smaller 'satellites' clustering around them. The shapes and sizes of the particles showed subtle variations when different alloys were used.

In their attempts to quantify them, LaTour's team identified 110 unique configurations overall – each affecting the yield, production rate and efficiency of the atomisation system. In future studies, LaTour and his colleagues now hope to discover new ways to optimise these values, without affecting the quality of the final product. With these advances, MolyWorks' Mobile Foundry is moving closer towards commercial success. Ultimately, this could make localised facilities for scrapping, atomising and manufacturing metal parts a more realistic prospect than ever before.

A Circular Economy

As both the shipping and manufacturing sectors look towards reducing their environmental impacts, the development of the Mobile Foundry comes at a crucial time. The potential for globally distributed metal recycling brought about by MolyWorks may represent a significant step towards achieving a circular economy in metal manufacturing. As the global economy continues to grow unabated, the Mobile Foundry, and technologies like it, could one day prove to secure our futures, without unleashing irreversible damage on the natural world.

Meet the researchers

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Andrew LaTour was awarded his degree in Chemical Engineering from San Jose State University in 2011. He has over 12 years of experience in Research and Development, and is familiar with a wide variety of equipment and processes, through the invention of chemical and material formulations, as well as novel equipment. Most recently, he was the co-founder of MolyWorks Materials Corporation, where he now works as Chief Innovation Officer.

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Matthew was awarded his BS degree in Manufacturing Engineering from California State University Chico, in 2001. He now has 15 years of experience in metallurgy R&D. He is an industry expert, having designed, fabricated, developed, and scaled up metallurgical systems. With a little help from Andrew and Chris, Matt built our first mobile foundry prototype in his front yard, utilising his homemade containerised machine shop to craft furnace components.

Christopher Eonta achieved his BS degree in Chemical Engineering from San Jose State University in 2011. He is an accomplished inventor and entrepreneur. With a strong background in chemical engineering and metallurgy, Christopher has invented metallurgical systems and brought together a skilled team of investors and talented individuals at MolyWorks Materials Corporation. Christopher has commercialised products, sold capital equipment internationally, and received strategic investments from two S&P 100 Companies.

KEY COLLABORATORS

Marc Pepi, Army Research Laboratory
Tim Phillis, Rock Island Arsenal
Andrew Clark and Valentine Sackmann, Air Force Sustainment Center
Danielle L Cote and Christopher Jeffrey Massar, Worcester Polytechnic Institute

FURTHER READING

US Patent 14/831,911, Mixing Cold Hearth Metallurgical System and Process for Producing Metals and Metal Alloys
US Patent 62/790,103, Method for Manufacturing Nickel-Based Superalloy Components Using Recycled Feedstock and Additive Manufacturing
US Patent 62/781,107, Method and System for Manufacturing Landing Gear Components Using Additive Manufacturing
US Patent 16,135,191, Deployable Manufacturing Center (DMC) System and Process for Manufacturing Metal Parts