9 3D metal printing – powder bed to part

ERIC A. JÄGLE
↘ *Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf*

3D printing of plastic parts is a standard procedure in many fields, but a lot of research work is still needed when it comes to metals. However, it is obvious that additive manufacturing, the specialist term for this technology, could potentially revolutionize metalworking and open up new fields of application. Our group at the Max-Planck-Institut für Eisenforschung develops procedures to improve the design of metal alloys for and through 3D printing.

Long-life turbine blades, customized implants for patients and ultralight but sturdy car bodies – these are just some of the potential fields of application for components that can be produced by additive manufacturing, in other words 3D printing. Additive manufacturing is the term used to describe all methods in which material is applied by a computer layer-by-layer to create a three-dimensional object.

One special additive manufacturing method is selective laser melting. With this method, a several hundred watt laser beam scans a thin layer of metal powder in a matter of seconds. This powder melts and cools down within thousandths of a second. A brush applies a new layer of metal powder and the laser once again scans the metal trace that has just solidified. This procedure is repeated until the desired workpiece is finished. You could say it arises from the powder bed like a phoenix from the ashes.

3D metal printing has a number of advantages over conventional production methods. Bodies with complex shapes can be manufactured "in one piece" without any welding, milling or bonding of individual components. At the same time, shapes can be adapted individually and so-called art-to-part concepts realized, i.e. designs with no prior adjustment of the production line. It is often impossible to manufacture creatively designed components using conventional methods on account of the technical limitations, but with additive manufacturing, any design, no matter how complicated, is in principle possible. For example, turbine blades with complexly shaped and therefore very efficient cooling ducts can be printed for power stations and aircraft that are exposed to extremely high temperatures. Constant cooling during operation protects the material, allowing higher operating temperatures and saving fuel. Parts with cavities can also be printed in automotive engineering, thus saving material as well as weight whilst still guaranteeing a high stability thanks to the correct statics.

One of the limiting factors for 3D metal printing at present is not the production method but the alloy, in

Group leader Eric Jägle (left) and his PhD student Priyanshu Bajaj fill the chamber of the 3D printer with metal powder. This is so fine it could easily be inhaled. Which is why they are both wearing protective clothing.

One example of the complexity of components that can be produced by additive manufacturing: the logo of the Max-Planck-Institut für Eisenforschung as a relief on 3D printed coins of stainless steel.

other words the material from which the component is to be made. Although numerous alloys are known for every field of application from the classic metalworking methods such as forging, casting or sintering, and some of these are even suitable for additive manufacturing, they do not exploit the full potential of this method because they have been adapted to conditions that have become irrelevant thanks to additive manufacturing. This is why the feedstocks for 3D printing still have to be developed. And this is the research focus of our group at the Max-Planck-Institut für Eisenforschung.

The speed, strength, and diameter of the laser beam influence the microstructure

One approach being pursued by our team is of particular significance for us because it holds out the promise of a more flexible use of 3D metal printing. Those metal powders that are commercially available consist of alloys with a fixed mixing ratio for the individual constituents. Every single powder particle consists of this metal mixture. Classic alloys are often unsuitable for additive manufacturing. However, ordering special alloys from a company is expensive and complicated, and what's more not every alloy composition is accessible this way. It would thus be ideal if powder from pure elements could be used in the desired mixing ratio. In this case, the different powder particles would only melt to form an alloy during printing.

To investigate this possibility, we used metal powders of iron, chromium and nickel and tested the influence of various parameters on the alloy's properties both before and during the printing process. We investigated the printed components in detail, cubes for simplicity's sake, by means of light and scanning electron microscopy as well as x-ray spectroscopy and

In-situ alloy design opens up further production paths for composite materials

chemical analysis methods. The result: the speed at which the laser moves over the powder bed, the intensity of the laser beam and its diameter as well as the thickness of the powder layer affect the microstructure, which primarily determines the properties of the component. But the really crucial factor is the period of time in which the individual powders exist in a molten form in the melt pool before they solidify and form a chemically homogeneous component. Because to ensure that the various elements, which originate from different powder particles, mix well, the melt pool has to be kept alive for a while. We have been able to confirm this with model calculations too.

This in-situ alloy design enables some huge time savings and great flexibility in research work. One only has to buy the pure metal powders, mix them to the desired ratio oneself to carry out experiments quickly and easily. What's more, it is possible to combine materials that are very hard to mix using classical methods, for example metal matrix composite materials. These consist of a metal matrix to which ceramic components have been added, for example, as a reinforcement. They are used in a number of different fields, such as power electronics as well as automotive engineering and the aviation industry.

The result: a material for application at very high temperatures

At the same time, in-situ alloy design opens up further manufacturing routes for composite materials, for example for oxide dispersion-strengthened alloys. These kinds of steel, ODS for short, are of interest for applications at very high temperatures. They would normally have to be produced by a very complicated mechanical alloying process in which oxide particles are introduced into the steel. We managed to do this directly with the in-situ alloy design. To this end, we mixed the inert gas otherwise used in the process (nitrogen or a noble gas such as argon) with carbon dioxide (CO_2). This is normally very inert in itself, but under the laser beam it is split into carbon monoxide (CO) and oxygen, which then react with and penetrate the material. Under these conditions, finely distributed oxide particles formed by themselves in the material. The result: a material that can be manufactured relatively easily, without mechanical alloying, and that is roughly 25 percent stronger at high operating temperatures up to 800°C than the base material without the strengthening oxide particles.

The industry's interest is aroused

The results to date are very promising and have already aroused interest in industry, which was very hesitant when it came to new alloys for 3D metal printing only a few years ago. This also holds true for another hopeful branch of research into so-called high-entropy alloys. This class of material is very interesting because it displays a high strength and is also resistant to temperature and corrosion. High-entropy alloys usually consist of five metallic elements, each of which occur in similar amounts in the alloy. We are currently involved in developing such alloys especially for additive manufacturing. This would clear the way for long-life turbine blades, customized implants, lighter car bodies and much more. ○