SAVING ENERGY IN THREE DIMENSIONS

More new products are being manufactured using additive manufacturing (3D printing) than ever before. Many of them are still visionary applications. However, actual components that are used in research and industry are also being manufactured in this way today. About a dozen Swiss suppliers use additive manufacturing processes to produce metal parts. Together with an industrial partner, a Zurich-based research team has investigated the energy consumption of additively manufactured products and compared them with conventional manufacturing processes. Conclusion: The additive manufacturing method requires a lot of energy, but yields products with high added value.

Feramic Managing Director Martin Hofer at the control panel of an AM system. The unit produces several workpieces simultaneously during a 12- to 48-hour run. Photo: B. Vogel

A technical report about the results of a research project in the field of industrial processes, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the magazine Maschinenbau (issue October 2022).

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View through the viewing window into the interior of an AM device: One of the two lasers can be seen as it melts a wafer-thin layer of metal powder, thus bonding it to a metal layer. Each laser is a highly focused beam of light with 400 watts of power. The AM process takes place under nitrogen to reduce the formation of smoke and spatter. Photo: B. Vogel

View of additively manufactured injection molds (see also figure on the left). In the round pieces, the cooling channels located inside the finished part are clearly visible. Photo: B. Vogel

Additive manufacturing regularly makes headlines. Thanks to the method, new products are constantly being created from a growing range of materials, enabling previously unheard-of applications. Much of it still sounds visionary, while other applications are already part of established industrial production processes. In Switzerland, there are so far about a dozen of companies that manufacture metal parts additively. One of them is Feramic AG, which generates annual sales of around 1.5 million Swiss francs and has six employees. The company moved into its new production facilities in Stallikon (ZH) in spring 2022.

Applied layer by layer

In Stallikon, are three production systems for additively manufactured metal parts, each housed in a sobering, man-sized enclosure. One can observe the action happens by looking through a glass window: There, one sees a base plate. A squeegee covers it with a wafer-thin layer of metal powder. A laser beam flits across the metal powder and melts it in places. Once the process is complete, the squeegee applies a new layer of metal powder, and the laser does its work again. In this way, the desired metal part grows on the base plate, layer by layer, each only a few micrometers thick. Within a few hours, metal parts are created in complex shapes that can hardly be produced using conventional manufacturing processes such as casting, machining or bending.

Feramic Managing Director Martin Hofer leads visitors to a display of additively manufactured metal parts. The workpieces consist of filigree lattice structures and feature intricate shapes, or are crisscrossed with tiny channels. "We produce special parts for machine and tool manufacturers, but also prototypes for industry and research," Hofer says. The part with the fine cooling channels, for example, is installed in machines for plastic injection molding. The channels enable an increase in productivity of up to 40%. Next to it is a part that is used as the articulated arm of a robot. Thanks to additive manufacturing, it is both stable and lightweight.

International research project

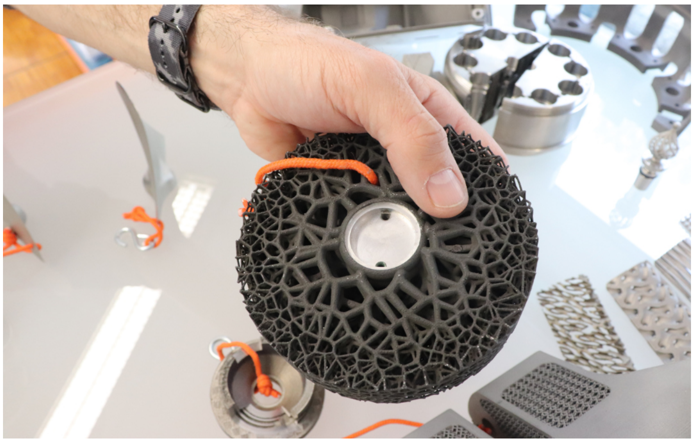
Each of the three machines that Feramic uses to additively manufacture metal parts uses 16 kW of electricity. That does not seem like a lot. However, the manufacturing process runs over several hours, and the manufactured parts are relatively small. In addition, post-processing the workpieces costs extra energy. Three years ago, Martin Hofer had the opportunity to learn more about the energy consumption of additive manufacturing. At that time, his company was approached to participate as an industrial partner for a particular research project. The topic is timely: Market studies forecast annual growth of 25% for additive manufacturing in the next few years.

In addition to Feramic AG, the Institute for Machine Tools and Manufacturing at ETH Zurich and Inspire AG, a private-law institution that promotes research collaboration between

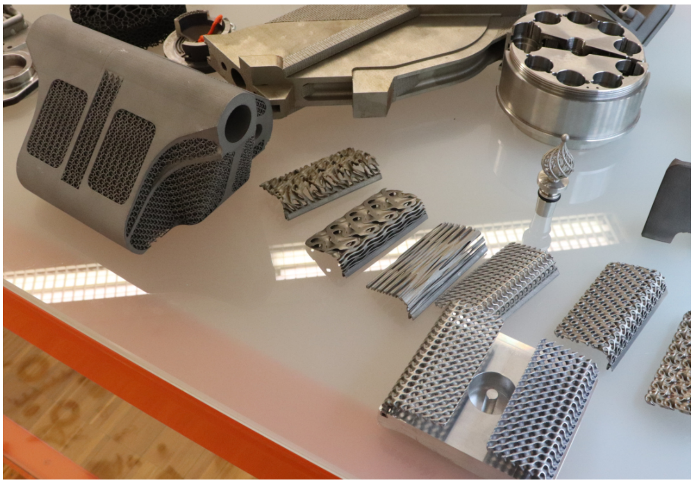
ETH Zurich and industry, were involved in the research project. The Swiss project was part of the CORNET project 'Ad-Proc-Add', which also involved academic and industrial partners from Belgium, Germany and Austria. The background to the international collaboration was the importance and, above all, the great diversity of the manufacturing industry in Europe, for which, isolated studies by individual research groups can be meaningless. Switzerland, as a major manufacturing location, producer and exporter of machine tools, has a direct interest in these issues.

Twelve workpieces examined as examples

As part of the international project, the Swiss research partners investigated how much energy is consumed in the additive manufacturing of mechanical components for machine tools, across the entire production chain. The research team estimated the consumption through literature studies and the evaluation of available data. In addition, the researchers quantified the energy consumption of additive manufacturing using twelve sample parts with weights ranging from a few grams to one kilogram as examples.



Additive manufacturing can be used to produce metal parts that are difficult or impossible to manufacture using conventional manufacturing processes. The bionic structure of this object – a design and cooling element – was modeled using special software. Photo: B. Vogel



Feramic AG uses five different materials for additive manufacturing: stainless steel, aluminum, tool steel, stainless tool steel or a cobalt chrome alloy. Photo: B. Vogel

ADDITIVE VS. SUTRACTIVE

Additive manufacturing (AM) refers to processes that produce metal parts by melting metal powder or wire. “Additive” means that the workpiece is created in this manufacturing process by adding material. This is in contrast to “subtractive” (or “machining”) manufacturing processes, in which excess material is removed from raw parts mechanically using cutting tools, for example by turning, drilling, milling or grinding.

An important additive manufacturing process is the laser powder bed fusion (LPBF) process, which has been in use for a good ten years. The workpiece is created layer by layer by melting metal powder using a laser beam. Wire Arc Additive Manufacturing/WAAM (also known as cladding) is another additive manufacturing process that has been around for decades. In this process, a wire is melted by means of an electric arc and an additional layer of material is applied to a workpiece. In certain cases, the WAAM process offers an energy-saving alternative to additive manufacturing in powder beds.

One key finding was that it is not only the electrical energy for the additive manufacturing process that counts when considering energy. It is also relevant to include the energy required to produce the metal powder used in the additive manufacturing process. This is because the metal powder is a semi-finished product, i.e. a prefabricated raw material that has already undergone a process step (which is also relevant in terms of energy). The powder, which is made from steel or another metal, contains energy in the order of 30 MJ/kg (steel) to 640 MJ/kg (high-strength titanium alloy Ti-6Al-4V). In addition, unavoidable powder losses occur during processing, and post-processing is necessary in every case, during

Approx. 80 % of all additively manufactured metal parts have to be mechanically reworked before they are delivered to the customer. Processes such as milling (picture), turning, grinding or sandblasting are used for this. Photo: B. Vogel

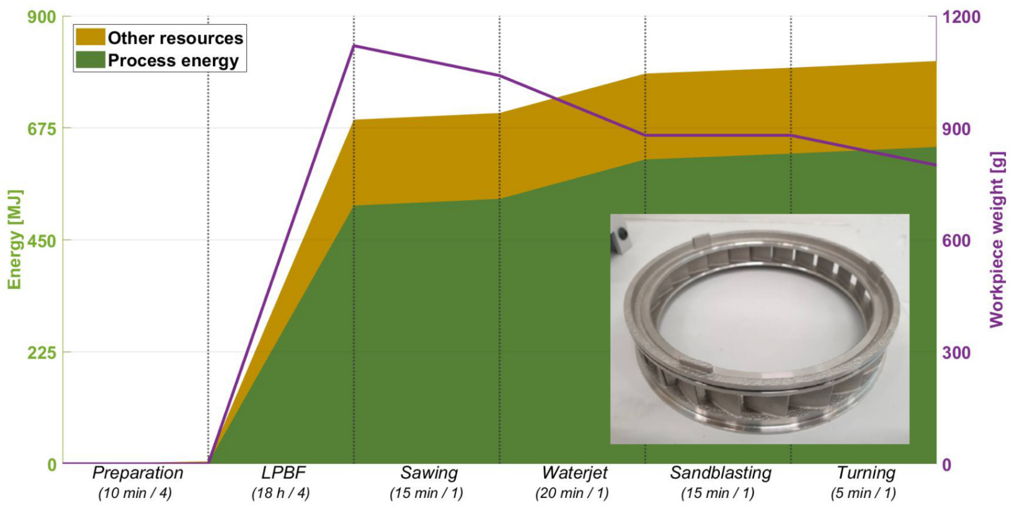
which part of the expensively produced material is removed again.

Against this background, it is not surprising that the additive manufacturing process requires more energy overall than manufacturing using a machining process (such as turning, drilling, milling or grinding), or a forming process, such as stamping or casting. "Manufacturing a workpiece in a powder bed sometimes requires ten times more energy than with conventional machining," says Inspire project manager Lukas Weiss. As an example, the trained electrical engineer points to the production of a noozle ring, the additive manufacturing of which requires 1011 MJ/kg (see chart below). Conventional production of the workpiece with casting would only require around 100 MJ/kg of energy. In this case, however, additive manufacturing has the advantage of a short processing time.

More Energy, but...

The example makes it clear that the tendentially higher energy consumption of additive manufacturing must be set against the advantages of this manufacturing method. In addition to a fast lead time, these include other advantages: the simple and fast production of prototypes, the production of workpieces with special design properties, a high degree of customer-specific adaptation, fewer production resources (e.g. molds) and shorter delivery times. "In order to assess the energy consumption of additive manufacturing, you must not only look at the manufacturing itself, but also include the entire life cycle of the workpiece," says Weiss. If a workpiece can be made particularly light thanks to additive manufacturing, it can sometimes save energy during its service life, for example when it is installed in a vehicle, which requires less drive energy thanks to its reduced weight.

In the future, additive manufacturing in the powder bed could be done with less energy. A concrete starting point for this is support structures. These are required for the additive build-up of certain shapes at all. They have to be removed during post-processing after the workpiece has been manu-



Using the example of a nozzle ring, the graphic shows the energy for additive manufacturing in the powder bed (green) and the gray energy contained in the powder (brown). Together, this gives the energy consumed to produce the workpiece, which in this case is 1011 MJ/kg. Energy is used not only for additive manufacturing (LPBF) per se, but also for post-processing (in the present case: sawing, water spraying, sand blasting, turning), which reduces the workpiece weight (purple line, axis on the right). Graphic: BFE final report factured layer by layer. If it is possible to manufacture a workpiece with fewer support structures, this saves energy both in manufacturing and in postprocessing. Feramic AG wants to investigate what savings can be achieved in this way in a new project with the Zurich University of Applied Sciences.

- The **final report** on the project 'EE-Proc-Add - Energy-efficient machining of additive components' is available at: www.aramis.admin.ch/Grunddaten/?ProjectID=44324

- For **information** on the research project, please contact Dr. Carina Alles (carina.alles[at]bfe.admin.ch), Head of the SFOE Research Program Industrial Processes.

- Further **technical articles** on research, pilot, demonstration and flagship projects in the field of industrial processes can be found at www.bfe.admin.ch/ec-prozesse.

The two sieving stations in the background are needed to sieve out the dirt particles that are produced during additive manufacturing from the production powder. Along the way, around 90% of the metal powder can be reused. The remaining 10 % is disposed of as scrap metal. Photo: B. Vogel

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