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Toward additive manufacturing

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A scientist using a 3D printer at the ARTC. Credit: A*STAR Advanced Remanufacturing and Technology Centre

Automation, robotics, advanced computer-aided design, sensing and diagnostic technologies have revolutionized the modern factory, allowing the building of complex products, from microchips to cars and even airplanes, with unprecedented cost-efficiency, scale and reliability. The modern factory represents the pinnacle of mass production technology, refined over a hundred years or more, to produce identical items for mass consumption at the lowest cost.

Every manufacturing line is uniquely designed and configured for one specific product or component. Setting up an assembly line to produce a new item is a costly and painstaking process, involving iterative design and prototyping within the constraints of available mass production technologies. This includes the creation and configuration of molds, installation and configuration of equipment, designing, testing and troubleshooting processes, and quality testing of the final product. The lengthy process results in long lead times and presents significant obstacles to item customization and the production of small batches or very complex pieces.

Additive manufacturing, known as 3-D printing, looks set to turn this traditional model on its head. In contrast to using a dedicated assembly line for a single item, additive manufacturing uses a single high-technology production line to create many different items without the design constraints and startup costs of conventional mass production.

"Additive manufacturing is today mainly used for high-value, high-complexity and low-volume production," says A*STAR's Advanced Remanufacturing and Technology Centre (ARTC) Senior Group Manager, Stuart Wong Sow Long. "With the advancement of technologies such as high-performance computing and sensor technology, however, the industrialization of additive manufacturing is accelerating."

The envisaged 'smart factories' seamlessly bring technologies such as the 'internet of things', cloud computing, advanced robotics, real-time analytics and machine learning together around a versatile additive manufacturing hub, and enable the production of customized products at mass scales, cheaply and quickly.

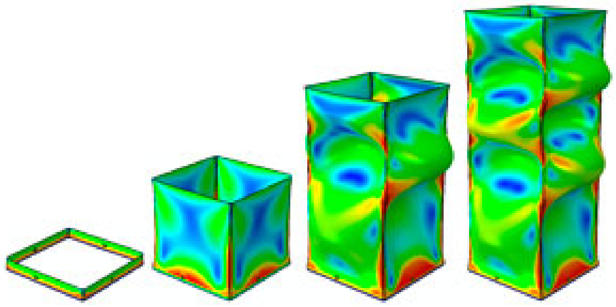
Stuart notes that "future factories will be able to create products that were not possible before, producing design geometry impossible to manufacture by traditional machining processes." Accordingly, A*STAR has established the Factory of the Future program at the Advanced Remanufacturing and Technology Centre to ensure that Singapore will become one of the key global players in this emerging sector.

The Rise of Additive Manufacturing

Although additive manufacturing has been around since the 1980s, the technology has advanced rapidly over the past few years. Many companies in the aerospace, automotive and machine tool production industries have introduced additive manufacturing for rapid prototyping as a cost-effective part of the design process, and it is increasingly being used for custom fabrication in medical applications, as well as dental products such as crowns.

"The product is built up layer by layer," explains Tan Teck Leong from A*STAR's Institute of High Performance Computing (IHPC). "This is in contrast to traditional 'subtractive' manufacturing, where material is removed to form the final product shape."

While thermoplastics are the most widely used materials for additive manufacturing, industrial objects typically need to be produced from metallic alloys, a more advanced manufacturing approach. In metal additive manufacturing, a volume of metal powder is precision heated using a laser or electron beam to fuse the metal into a contiguous whole with almost no material waste. "Future factories will use additive manufacturing because it allows practically any design to be printed, including intricate shapes such as gears, engines and blades," says Leong.



A simulation of the additive manufacturing process of a thin-wall structure, showing the distortion experienced by the part as it is being built. Color scale: Red = high residual stress — blue = low residual stress. Credit: A*STAR Institute of High Performance Computing

Persistent drawbacks of printing-based methods need to be addressed before it can compete. These drawbacks center around the poorer mechanical properties of printed parts, compared with cast or machined parts.

"Particularly for metallic materials, improving mechanical properties is one of the biggest challenges in additive manufacturing," says Leong. "Many processing factors, including powder morphology, laser power and speed, need to be perfected in order to minimize the formation of defects such as pores and brittle impurities, which can compromise the mechanical properties of the printed product."

Game-Changing simulations

One of the most significant ways in which A*STAR researchers are contributing is through simulation of the manufacturing process using fundamental principles of materials physics.

"Physics-based simulations support additive manufacturing in multiple ways," says Guglielmo Vastola from the IHPC. "For large end users of 3-D printed parts, simulations show if and where the part could fail during the manufacturing process, and can therefore suggest the optimal way to print the product before sending the part to the printer. The equipment and raw materials are very expensive, so this means direct savings. The manufacturers of 3-D printers can also use our simulations to understand the exact functioning of their machines, and to get clues on how to further improve them to increase product quality and reliability."

The IHPC is leading a cross-disciplinary effort to develop a comprehensive simulation toolkit for additive manufacturing, involving fluid dynamics to simulate the flow and melting process of the powder precursors during laser melting, photonics to simulate the interaction between laser and processing material, and materials science to simulate the microstructure, chemical composition and mechanical properties of the final product.

"Modeling and simulation will be the 'killer app' for additive manufacturing," says Vastola. "Because additive manufacturing is such a complex and difficult process, and at the same time so economically important, developing simulation software to support the technology will be a tremendous contribution."

Opportunities and challenges

"The classic example of the benefits of additive manufacturing is the engine fuel nozzle by GE, where the transition from traditional to additive manufacturing translated into a reduction from 19 components to just one component that is 25 per cent lighter, 5 times more durable, and that increases fuel efficiency by 15 per cent," says Vastola. "It became possible to produce a complex part like a fuel nozzle easier and faster than before, in a single component run. And the design can be made even more complex if need be, because manufacturing is not a constraint anymore. That is the essence of the opportunity."

To realize these benefits, A*STAR researchers are working hard on the two main obstacles to a commercially-ready future factory concept: repeatability, and standardization. The repeatability of the process is critical. Currently, fabricating the same part using the same material, but on different machines will result in different final product quality. Even starting the part from a different position on the same machine can result in differences in mechanical properties. Standards are under development, but the additive process is very complex and therefore standardization is remains a challenging task.

"In five to ten years, we will see more parts being moved from traditional to additive manufacturing on a purely economic basis," says Vastola. "The GE fuel nozzle can be regarded as the pioneer of many more parts to come. And as the technology becomes more widely adopted, it should move upstream all the way to parts designers. Then, once the freedom of complexity is embraced at the design level, we will start to see truly 'new' parts that simply would have never been thought of before. Additive manufacturing is truly an enabling technology, and the time is right for this technology to enter the shopfloor as the foundation for future factories."

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