Wire-Laser Metal 3D Printer AZ600

Authors: *Maiku Hayashi*, Nobuyuki Sumi**

** Industrial Mechatronics Systems Works*

Abstract

Additive Manufacturing (AM, 3D printing) is seeing broader application in the manufacturing industry.

Mitsubishi Electric has developed the wire-laser metal 3D printer “AZ600,” which is the first in Japan*1 to adopt a combination of metal wire and laser as a material and a heat source respectively. The AZ600 is equipped with an AM process control function that detects the printing status using various sensors and coordinates machining conditions and axis speeds, achieving stable printing and high precision. Furthermore, by using Mitsubishi Electric’s unique dot forming, it is possible to suppress thermal distortion and oxidation. In cases where AZ600 is applied to AM, processing time, manufacturing costs, and material waste can be expected to be reduced, contributing to carbon neutrality. Furthermore, we can expect more stable quality in work dependent on individuals, and better response to needs for automation and labor-saving.

1. Introduction

In recent years, the manufacturing industry has experienced soaring raw material prices and longer delivery times due to COVID-19 outbreaks and growing geopolitical risks. Carbon neutrality has also garnered increasing attention in countries worldwide. Since AM can finish materials in near-net shape (a state close to that of a finished product), it is expected to reduce costs by reducing waste materials, shorten delivery times, and reduce energy consumption. Furthermore, there is a design method specifically for AM called Design for Additive Manufacturing (DfAM), and this makes maximal use of the characteristics of AM. If this type of design is used, we can achieve higher functionality as well as conserve resources. In AM, printing is done using digital data, such as 3D-CAD data. This is a digital manufacturing technology that enables printing by anyone, anywhere, provided they have the equipment and necessary processing conditions. As a result, the technique is also garnering attention as a technology for realizing Digital Transformation (DX).

We developed the wire-laser metal 3D printer AZ600 against this backdrop. This system can contribute greatly to society through AM manufacturing—from solving production problems to protecting the environment. The Directed Energy Deposition (DED) method combines metal wire (material) and a laser (heat source), and this has various advantages for the user. However, the method requires development of very difficult control mechanisms, so only certain equipment manufacturers can enter the field. We have realized a wire-laser metal 3D printer for the first time in Japan*1. This was achieved by leveraging the technical synergy of our company’s products: Computerized Numerical Control (CNC), laser machining equipment, and wire electric discharge machining equipment. The AZ600 first went on sale in the Japanese market in March 2022.

2. Features of the Wire-Laser Metal 3D Printer AZ600

2.1 Equipment specifications

Appearance of the AZ600 is shown in Fig. 1(a), and specifications are given in Table 1. DED is used as the printing method. The system is equipped with three Cartesian axes (XYZ) on the processing head side, and two rotary table axes (incline axis and rotation axis) on the workpiece side. Simultaneous 5-axis control is performed using CNC made by our company. This enables stable no-drip printing by varying orientation on the workpiece side, even with shapes that have complex curved surfaces or overhangs. As the heat source laser, the system is equipped with a continuous-wave type fiber laser oscillator, and models with two different outputs (2 kW and 4 kW) can be selected.

Figure 1(b) shows the situation near the processing point. The intersection of the perpendicularly irradiated laser and the metal wire supplied from the wire nozzle becomes the processing point. At the

*1 According to our research, February 24, 2022 processing point, integrated metal is produced by simultaneous fusing of the substrate and metal wire while suppressing oxidation with a shield gas (argon) supplied coaxially with the laser. Commercial φ1.2mm welding wire can be used as the metal wire. Replacement work has been made safer and more efficient by setting the metal wire spool at the worker's feet.

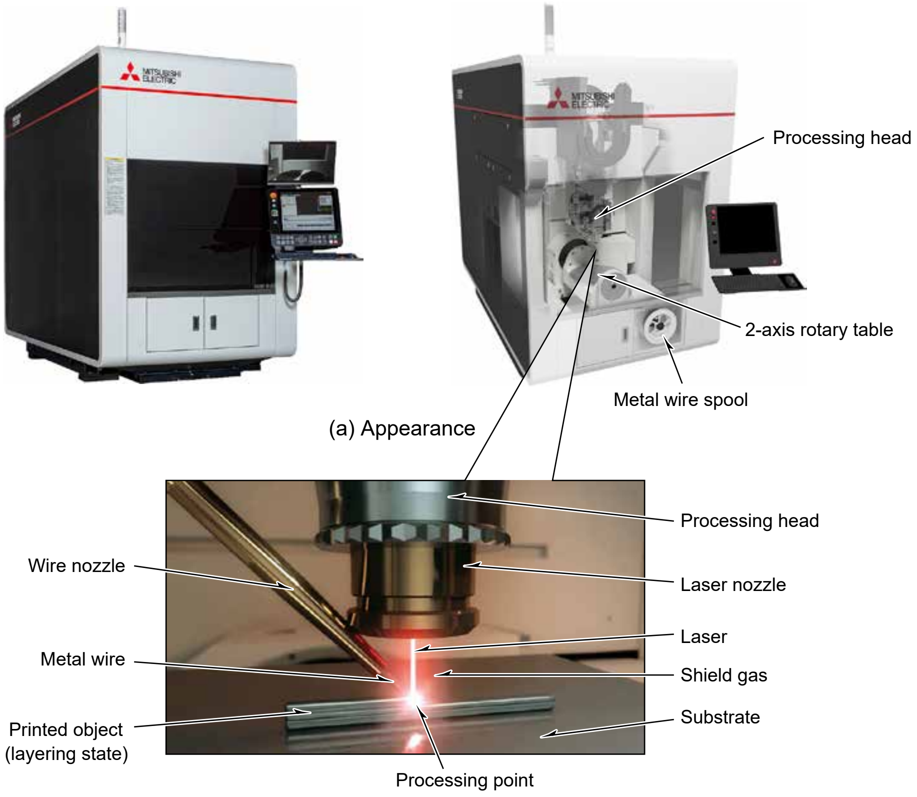

Fig. 1 Metal 3D printer AZ600

Table 1. Specifications of metal 3D printer AZ600

Printing method		DED
Supplied material		Metal wire (standard diameter: φ1.2mm)
Heat source		Fiber laser (CW)
Laser rated output		2kW or 4kW
Outer form	Width × Depth × Height (mm)	1,600 × 2,900 × 2,500
	Main unit weight (kg)	Approx. 7,000
Axis movement range	X × Y × Z-axis (mm)	600 × 600 × 600
	B(A)-axis (°)	±120
	C-axis (°)	360
Workpiece	Maximum size (mm)	500 × 500 × 500 (φ500 × 500)
	Maximum weight (kg)	500

Use of wire as the supplied material enables cleaner and safer material handling than powder methods. Printing yield is higher, and probability of producing air holes in the printed object is low(1). Material switching is also comparatively easy.

By using a laser as the heat source, printing can be done with higher precision than with the arcs and electron beams used with other DED methods. There is also no need to provide a vacuum chamber, as in the case of an electron beam.

2.2 Monitoring function and AM process control function[2]

The processing head is equipped with sensors and a camera. It monitors things like height on the workpiece side, and status of the molten pool formed at the processing point, and a display is provided on the equipment's operation screen. Also, the CNC is equipped with a function for controlling the printing process (Fig. 2). With this function, the previously described monitoring results are reflected in axis movement commands by the Numerical Control (NC) program, and the initial output command for processing conditions (i.e., laser output and feeding speed). Also, axis movement commands and processing condition output commands are performed by coordinating axis movement control, laser output control, and wire feeding control so that factors like wire end position, bead width, and bead height are appropriately maintained during printing. In this way, we strive for greater stability in the printing process, and greater precision of the printed article.

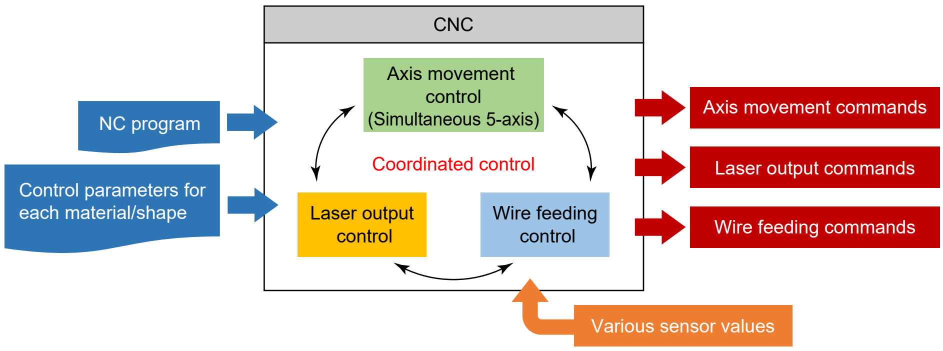

Fig. 2 AM process control function

2.3 Printing processes: "Line forming and dot forming"

This equipment is capable of dot forming[3], where a dot-shaped bead is formed by performing wire feeding and laser irradiation in a pulsed fashion. Figure 3 shows the printing process for one layer with the ordinary line forming process and the dot forming process. The printed object is formed in three dimensions by stacking and lining up these layers.

In line forming, a line-shaped bead is formed in a single layer by continuously performing laser irradiation, wire feeding, and axis movement, as indicated in Fig. 3(a).

In dot forming, on the other hand, a dot-shaped bead is formed by performing laser irradiation and wire feeding for just the specified time while axis movement is stopped, as indicated in Fig. 3(b). After that, the system moves axes to the next position designated by the NC program, and a dot-shaped bead is formed again by the same process. A single layer is formed by repeating this process.

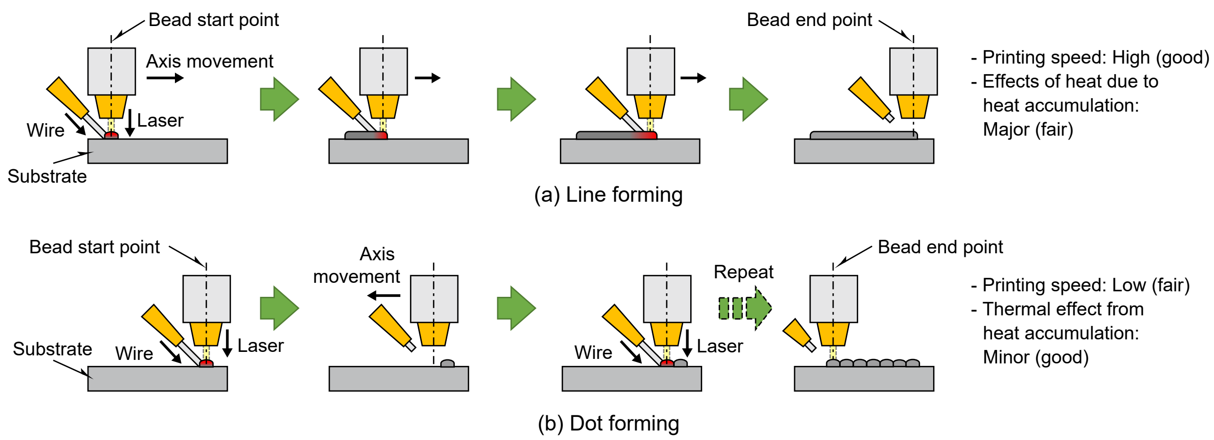

Fig. 3 Schematic diagrams of single-layer printing

In line forming, heat input per unit time is higher than dot forming, so there are cases where significant heat accumulates, and printing precision drops due to thermal strain. However, line forming has the advantage that printing speed is high.

On the other hand, although dot forming is slower than line forming, there is little thermal strain on the printed article due to heat accumulation, and printing precision is high. It is also possible to lengthen the shield time at the processing point, and thus printing can be done while suppressing oxidation, even with materials averse to oxidation like titanium alloy.

Printing is done by selectively using line and dot forming to suit the printed shape, printing location, and required quality, based on the characteristics of each printing process.

3. Effects of Use

3.1 Near-net-shape

Figure 4 shows an example of using near-net-shape for a marine propeller. Additive manufacturing of the blade part is done via line forming and dot forming, using stainless steel 17-4PH wire, on a base consisting of a φ99mm cylinder made of stainless steel 304. The cylinder base can also be fabricated by additive manufacturing, but in this case, fabrication can be done more quickly and inexpensively by lathe turning. Fully exploiting the advantages of AM, by skillfully combining with techniques other than AM in this way, is one element of DfAM for DED.

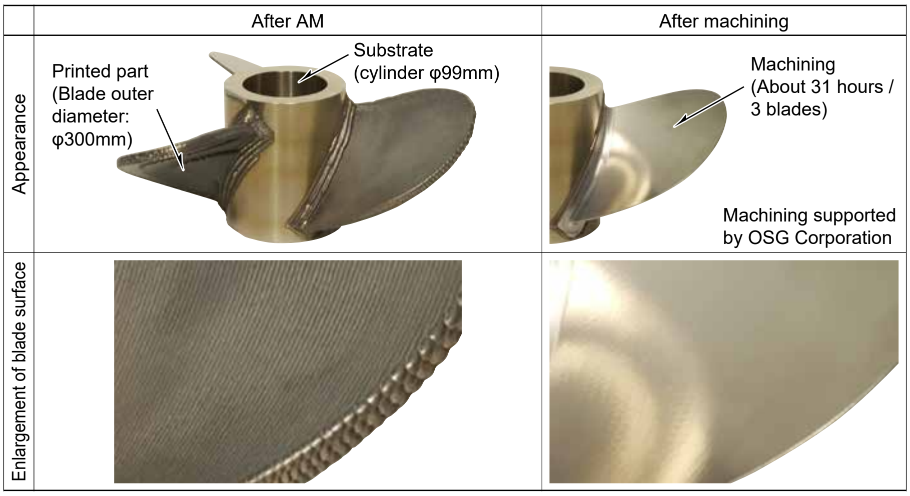

Fig. 4 Marine propeller produced using AM method

Outer diameter at the blade end is φ300mm, and printing time for a total of three blades is about 9 hours. Machining is done next, as the process after additive manufacturing, to achieve product precision. Machining time is about 31 hours for a total of three blades.

Figure 5 shows the results of comparing the conventional method (machining only) and the AM method (additive manufacturing + machining). Figure 5(a) shows a comparison of total processing time. The conventional method requires approximately 168 hours to process as it is machined from solid stainless steel 17-4PH with a diameter of 312mm. With the AM method, on the other hand, processing time can be greatly reduced by forming near-net-shape blades, and then doing finishing only (without rough machining) as the subsequent process. This method takes about 40 hours in total. By using additive manufacturing, processing time can be reduced by about 80% compared to the conventional method.

Next, Fig. 5(b) shows a comparison of the amount of material waste. With the conventional method, about 95% of the material becomes waste in the form of cutting chips. The AM method can reduce the amount of material waste by as much as 96.5% compared to the conventional method, and thus energy consumption can be curbed, helping to reduce carbon emissions.

Finally, Fig. 5(c) shows a comparison of manufacturing cost. The amount of material waste in Fig. 5(b) can be regarded as the amount of machining, and since stainless steel is a hard-to-machine material, machining must be done by consuming large amounts of comparatively-expensive end mills made of carbide, etc. The AM method, on the other hand, requires wire and shield gas as consumable supplies, but the amount of machining is reduced. Therefore, end mill consumption and material volume are decreased, and manufacturing costs can be reduced by 78%.

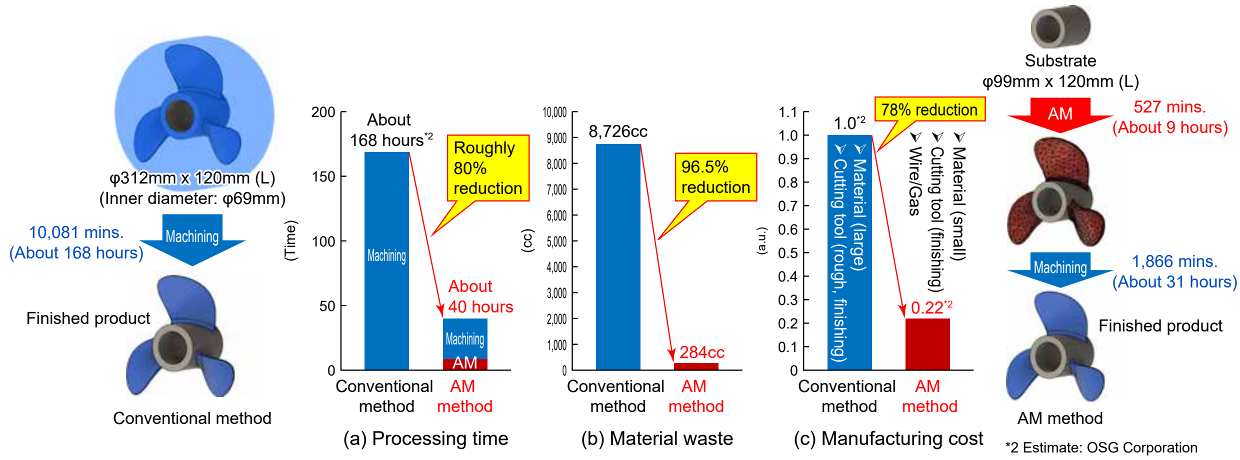

Fig. 5 Comparison of conventional and AM method

3.2 Multi-material

Figure 6 shows an example of use for a drill used in the petroleum or natural gas industry, etc. These drills are used to cut through high-hardness materials such as sediments, in harsh environments where high-temperature seawater and highly-corrosive gases spurt out. The possibility was considered of fabrication via the conventional method of cutting a hard-to-machine, wear/corrosion-resistant material, but that was unrealistic because it is time-consuming and costly. Therefore, a key issue is the trade-off between cost and service life.

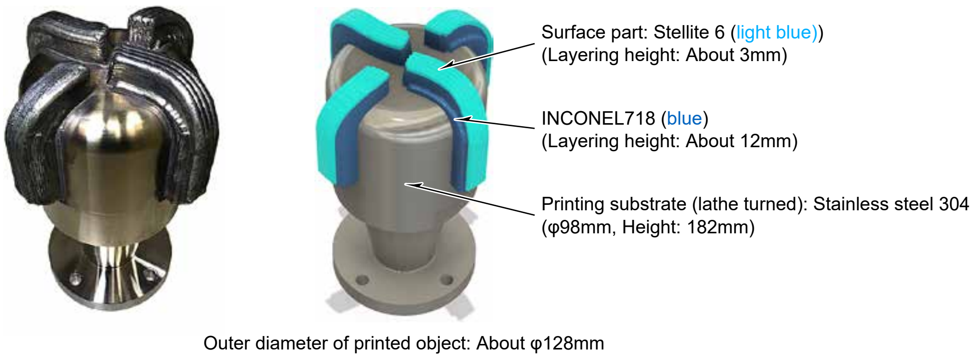

Fig. 6 AM method using heterogeneous materials

In this example, each blade body was first produced through additive manufacturing using wire made from INCONEL*3 718, a nickel-based alloy which has outstanding corrosion resistance to many media under high temperatures. Then each blade surface was coated, via additive manufacturing, using wire made from Stellite*4 6, a cobalt-based alloy with outstanding wear resistance. Printing time is about 2.5 hours in total. Stainless steel 304 was used as the substrate in consideration of material cost, machinability, and corrosion resistance.

Higher part functionality and lower manufacturing cost can also be achieved by adopting a multi-material approach, where necessary materials are used at the necessary points.

*3 INCONEL is a registered trademark of Huntington Alloys Corp.
*4 Stellite is a registered trademark of Kennametal Inc.

3.3 Overlay repair and welding

Figure 7(a) shows an application example assuming the repair of die-casting molds. 10mm × 45° corner chamfer simulated defects were produced at the corners of a workpiece made of H13 tool steel hot work tool steel, and overlay repair was carried out through additive manufacturing using maraging steel wire. Printing time was 4 minutes per corner. After that, part of the printed section was cut and polished. No flaws like cracks or voids were evident in the repaired part, and it was confirmed that the original workpiece form could be restored.

Figure 7 (b) is an example of applying groove welding. The groove angle and depth were so large as 30° and 15mm, making it one of the most difficult types of groove welding. In this example, the groove part of a 200mm long stainless steel 304 workpiece was welded with a multi-layer stack of 17 layers using stainless steel 308L wire, and the processing time was approximately 10 minutes.

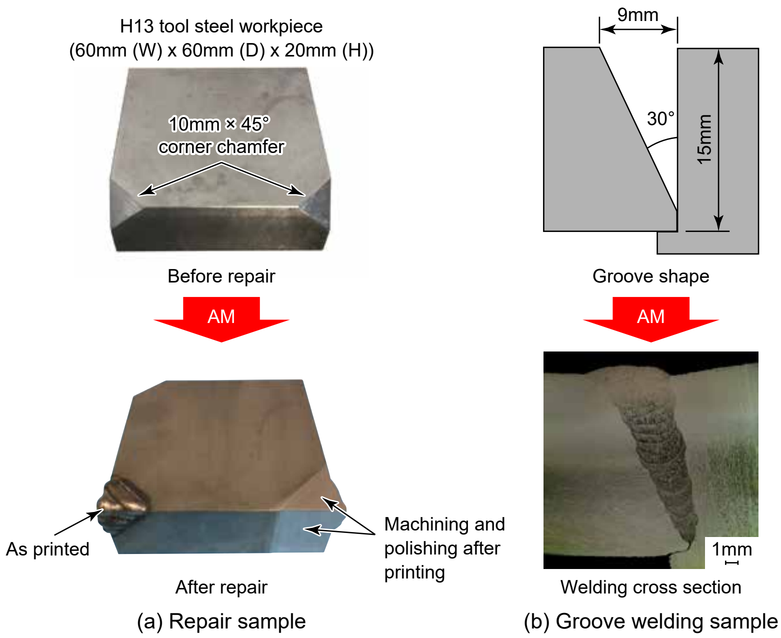

Fig. 7 Overlay repair and welding

The work in both cases required experience and know-how and was therefore individualized, leading to problems such as labor shortages and unstable quality. By performing these works using the AZ600, it is possible to not only stabilize quality but also meet needs for automation and labor savings.

4. Conclusion

We have described the features and effects of using our company's wire-laser metal 3D printer AZ600. This technology can shorten manufacturing time, and reduce material waste and tool depletion. It can therefore be expected to contribute to carbon neutrality.

The features of AM technology will have to be correctly understood for AM technology to come into wider use. We at Mitsubishi Electric will expand applications of the AM method by utilizing the AZ600, based on mutual understanding of AM technology with our customers. We will also continue development, by enhancing functionality of the system to meet market needs, so we can offer customers greater use value.

References

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