

THE DEVELOPMENT STATUS OF THE NATIONAL PROJECT BY TECHNOLOGY RESEARCH ASSOCIATION FOR FUTURE ADDITIVE MANUFACTURING (TRAFAM) IN JAPAN

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Abstract

The Ministry of Economy, Trade and Industry (METI) of Japan established Technology Research Association for Future Additive Manufacturing (TRAFAM) in order to develop AM technology in FY2014. The association's mission is twofold; to develop metal Additive Manufacturing technology and to develop binder jetting-type machine for the rapid production of sand molds. The goal of TRAFAM project is the development of innovative metal AM systems that will meet the world's highest standards and the development of AM technology for high value-added products for aerospace, medical, and transportation industries etc. In this paper, the latest development status of the project, especially the development status of the electron beam PBF type machines, the laser PBF type machine and the laser DED type machines, is introduced. In addition, the numerical simulation software for metal AM based on multi-scale and multi-physics model is introduced.

Introduction

The Ministry of Economy, Trade and Industry (METI) established a study group on New “Monodzukuri (manufacturing)” in October, 2013 because Japan lags behind the U.S.A. and Europe in addressing Additive Manufacturing (AM) technology. The study group proposed the future directions of “Monodzukuri”, and finally compiled the results of the meetings into a report [1]. Also the study group offered the issues to tackle; (1) developing technology in which devices, materials and software, (2) developing environments, (3) fostering human resources, and (4) seeking ideal approaches to creating enterprises. On the basis of this offer, METI invested about \$36.5 million in FY2014 to establish a new research association, Technology Research Association for Future Additive Manufacturing (TRAFAM), in order to develop metal AM systems and a binder jetting machine for producing sand molds.

In this paper, the latest development status of the project, especially, the development status of the electron beam powder bed fusion (PBF) type machines, the laser PBF type machine and the laser directed energy deposition (DED) type machines is introduced. In addition, the simulation software for metal AM based on multi-scale and multi-physics model developed by TRAFAM is introduced.

The role of TRAFAM

METI invested about \$36.5 million in FY2014 to launch a new research association, Technology Research Association for Future Additive Manufacturing (TRAFAM) [2], in order to develop metal AM systems and a binder jetting machine for producing sand molds rapidly. The members of TRAFAM include three academic institutions and 34 companies in FY2018 as shown in Fig.1. The mission of TRAFAM project is to establish a new manufacturing industry in Japan centering on AM systems that will give rise to the next generation of innovative products. The goal of TRAFAM project [3] is the development of the innovative AM machines meeting the world's highest standards as shown in Table 1;

- Enhanced speed (Approximately 10 times the speed at FY2013)
- Enhanced accuracy (Approximately 5 times the accuracy at FY2013)
- Upsizing (Approximately 3 times the molding range at FY2013)
- Multi-material structure (Different types of metal materials can be used)

TRAFAM developed the PBF type and DED type of AM machines with electron beam or laser beam systems. The software for controlling AM machines and the production technology of metal powder for AM technology are developed in order to make AM machines higher performance.

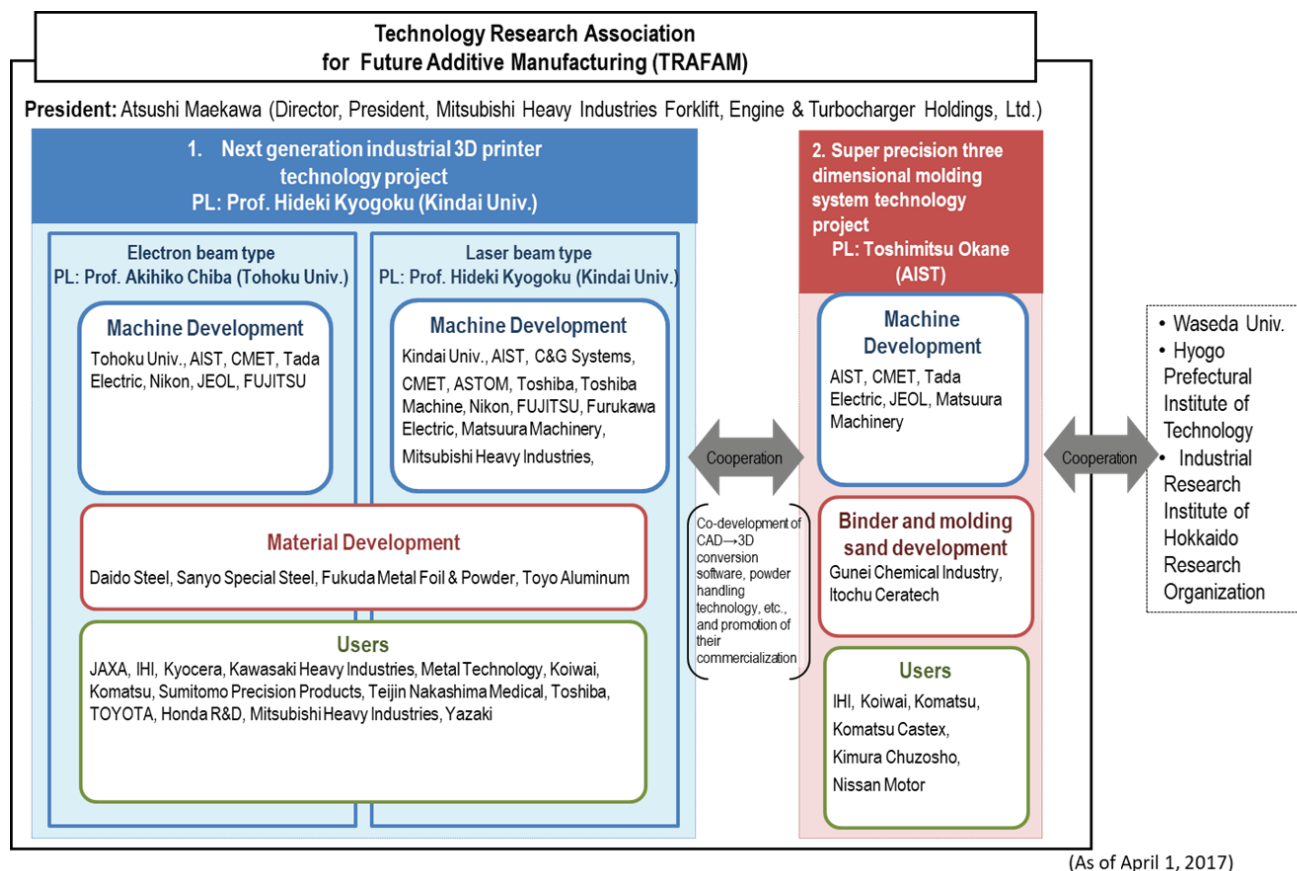


Fig.1 Corporative structure of TRAFAM

Table 1 Final goal (to be reached in FY2018)

	Light Source	Product Size (mm)	Modeling Speed (cc/h)	Dimensional Precision (μm)
Type I	EB	Large (1000 x 1000 x 600)	500	50
Type II	EB	Small (300 x 300 x 600)	500	20
Type III	LB	Large (1000 x 1000 x 600)	500	20
Type IV (Deposition method)	LB	Small (300 x 300 x 300)	500	20

The development status of TRAFAM project

The status of development in the next-generation 3D printing technology project at the end of FY 2017 is mainly introduced.

(1) EB-PBF machines

JEOL developed an EB-PBF prototype machine (first machine, Fig.2(a)) with an electron gun of LaB6 cathode and an electron optic system for 6 kW. The second EB-PBF machine (Fig.2(b)) which is mainly used for TiAl alloy is equipped with an electron gun of LaB6 cathode and an electron optic system at 10 kW and a prevention system of electric discharge. Examples of trial products fabricated by the first machine are shown in Fig.3. JEOL is also developing a dispersing process technology of multi-material powders as shown Fig.4.



(a) First machine



(B) Second machine

Fig.2 EB-PBF machines developed by JEOL

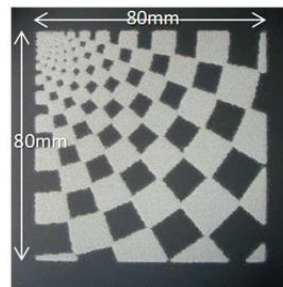
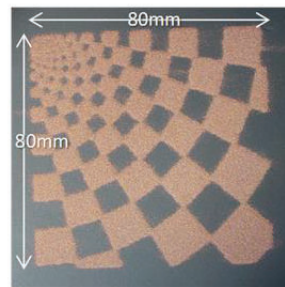


(a) Closed impeller (Early stage)



(b) Opened impeller (middle stage)

Fig.3 Examples of trial products by JEOL machines



Copper and M2 powder

Accuracy of positioning: 200 μ m

Fig.4 Results of multi-material powder dispersion

(2) Large-scale EB-PBF machine

TADA ELECTRIC CO. LTD., which is one of MITSUBISHI ELECTRIC CO. group, developed a large-scale EB-PBF prototype machine as shown in Fig.5. The build size is 500x500x600 mm and the rated output is 6 kW by the original long lifetime cathode (over1000 h). The high-speed deflection of electron beam control system was developed to control an electron beam on a large area of powder bed stably. Also, the powder recycle system for large-scale machine was developed as shown in Fig.6.

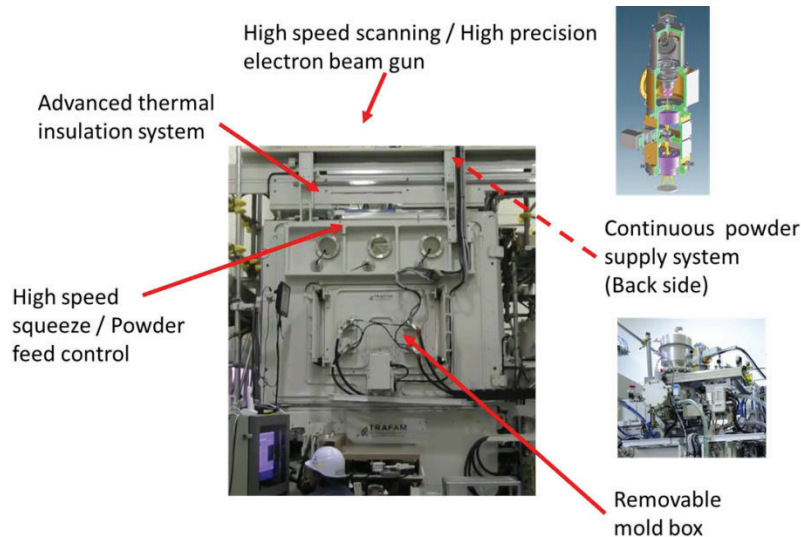


Fig.5 Large-scale EB-PBF prototype machine developed by TADA ELECTRIC

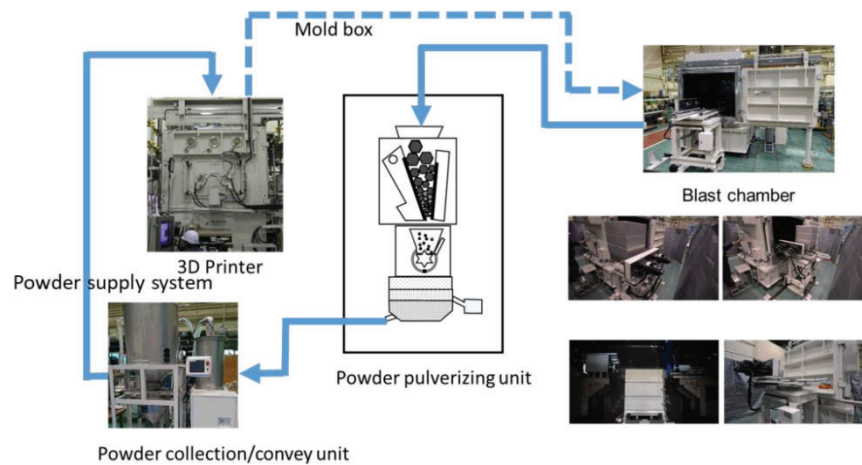


Fig.6 Powder recycle system for large-scale machine

(3) Large-scale LB-PBF machine

MATSUURA MACHINERY CO. developed a large-scale LB-PBF prototype machine (Fig.7(a)) and a large-scale LB-PBF second machine (Fig.7(b)). The build size is 600x600x400 mm. These machines are equipped with high power lasers of 1 kW single mode fiber laser and 2 kW single mode fiber laser for high-speed production and a multi-laser control system for wider area. Fig.8 shows an example of a large-scale pipe model of Inconel 718.



(a) Large-scale prototype machine
(b) Large-scale second machine
Fig.7 Large-scale LB-PBF machines developed by MATSUURA MACHINERY

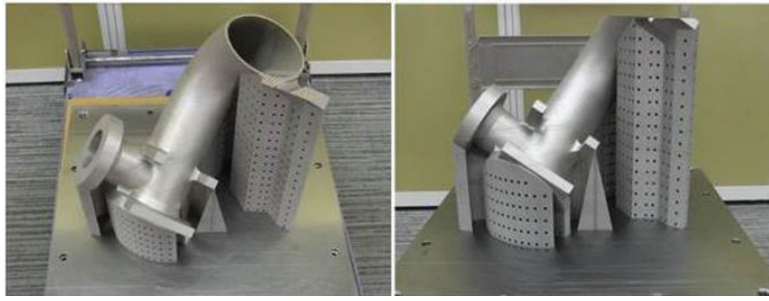


Fig.8 An example of a large-scale pipe model (INCONEL718) ($400 \times 350 \times 350$ mm)

(4) LB-DED machine

TOSHIBA CO. and TOSHIBA MACHINE CO. developed a LB-DED prototype machine (Fig.9) equipped with a 6 kW laser and a high performance nozzle. This machine type is multi-layer and the build speed is 510 cc/h at maximum. An example of a complex-shaped pipe with accurate and smooth surface owing to not only a high performance nozzle but also the CAM software for 5-axis control & multi-material DED is shown in Fig.10.



Fig.9 LB-DED multi-layer prototype machine

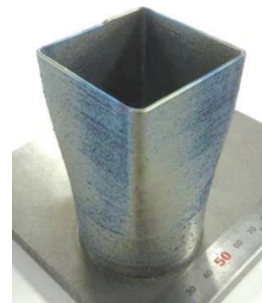


Fig.10 An example of complex-shaped pipe (INCONEL 718)

A large-scale LB-DED prototype machine was developed as shown in Fig.11. The specifications are as follows:

- Maximum dimension of built parts: 2000 mm in diameter x1000 mm in height
- Laser power for building: 6 kWx2
- Number of axis: Head 3 axis (Y, Z, A), Table 2 axis (X, C)

An example of a large fan case after machining is shown in Fig.12.

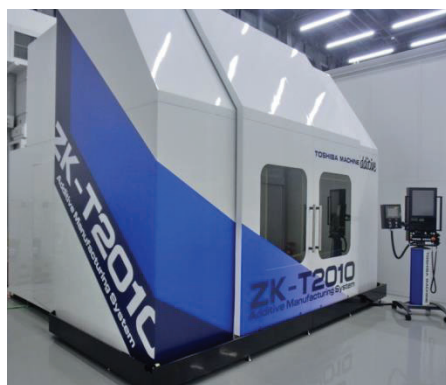


Fig.11 Large-scale LB-DED prototype machine



Fig.12 An example of fan case after machining
(Size: $\phi 710 \times h400 \times t10$ mm, Black area is as-deposited.)

(5) LB-DED and Milling hybrid-type machine

MITUBISHI HEAVY INDUSTRIES MACHINE TOOL CO. LTD. developed a LB-DED and milling prototype machine (Fig.13) equipped with a 6 kW laser and a high performance nozzle. Examples of a hollow body fabricated on a shaft are shown in Fig.14. The build speed is 500 cc/h at 6 kW at maximum, and the powder is able to switch to different one. This machine is suitable for manufacturing larger parts, repairing and printing different powders or functionally graded materials. The monitoring feedback of this system was developed so as to manufacture parts with high quality stably. The commercial machine is shown in Fig.15. The CAM software for 5-axis control & multi-material DED was developed in collaboration with the DED group as shown in Fig.16.



Fig.13 LB-DED & Milling prototype machine



Fig.14 Examples of hollow body fabricated on a shaft (SUS316L & INCONEL 718)



Fig.15 LB-DED commercial machine

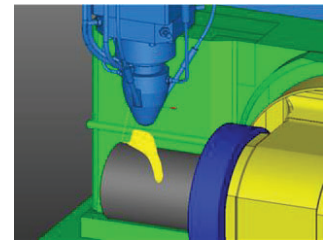
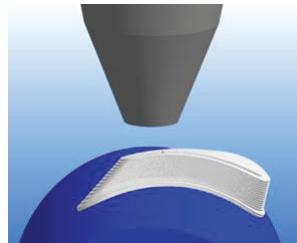


Fig.16 CAM software for 5-axis control & multi-material DED

Development of simulation software for metal AM

The development of numerical simulation is one of the most significant issues not only to manufacture high-quality products but also to realize “Digital Twin” for AM processes. The numerical simulation software analyzing the melting and solidification phenomena, the prediction of microstructure and the thermal deformation has been developed on the basis of multi-scale modeling technique and multi-physics simulation. Figure 17 demonstrates the schematic illustration of multi-scale modeling strategy for the AM process in TRAFAM project. The micro-simulation for melting-solidification analysis based on a two-fluid model and the thermal deformation simulation using inherent strain method were developed.

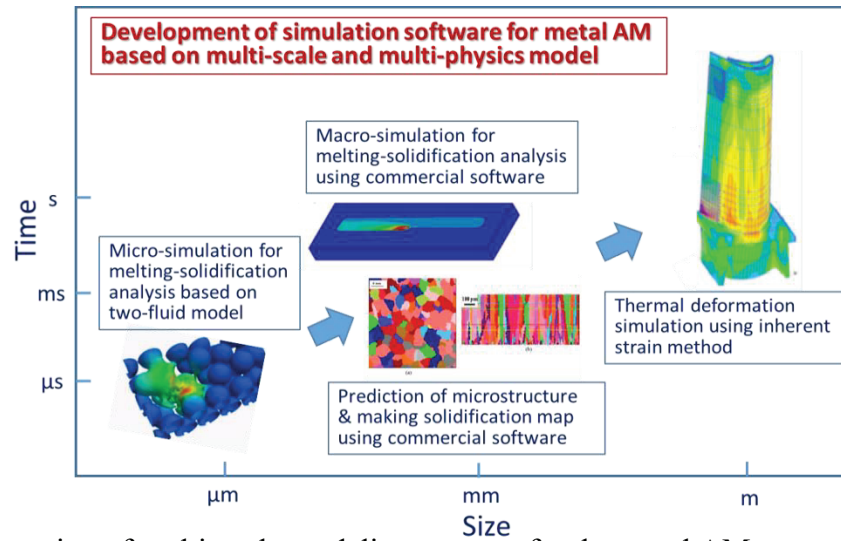
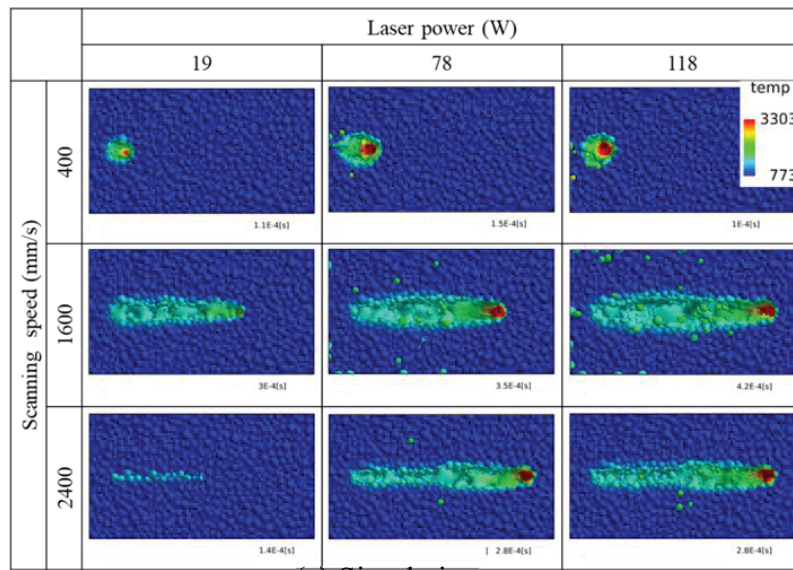
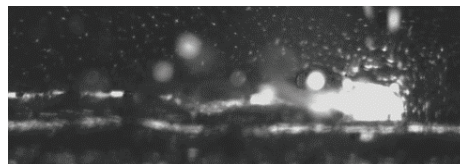


Fig.17 Schematic illustration of multi-scale modeling strategy for the metal AM process in TRAFAM project

The numerical simulation software of melting and solidification phenomena in metal PBF process was developed on the basis of a two-fluid model. The significant physical phenomena during melting and solidification such as keyhole, plume, and spatter generation due to interfacial pressure difference between gas and liquid phases can be treated using this software [4]. The gas-liquid two-phase flow is treated with the Eulerian-Eulerian two-fluid model. Figure 18 shows the top view of single track of Inconel 718 by simulation. The scattering of the spatter of melting metal as well as the melt pool are able to be observed. In the case of the one-fluid model [5], although the rolling waves of the molten metal surface can be expressed, the scattering of the spatter cannot be simulated. As a result, the simulated result is similar to the experimental one shown in Fig.18(b).



(a) Simulation



(b) Experimental result

Fig.18 Melting and solidification phenomena. (a) Top view of single bead molding processes of Inconel 718 by simulation [4], (b) Experimental result of Inconel 718 observed using a high-speed camera

Macro-simulation for melting-solidification analysis using commercial software was performed and predicted fabrication conditions such as laser power, scan speed, hatch pitch and so on. The analysis of melting-

solidification phenomenon of a melt pool by a computational fluid dynamics (CFD) was performed, and the solidification maps, displaying solidification microstructure as a function of solidification rate and thermal gradient at the solidification front, were determined by using a cellular automaton simulation.

In addition, the thermal deformation simulation software for LB-PBF, EB-PBF and DED using inherent strain method was developed. The results analyzed by the inherent strain method coincided considerably with those of the thermal elastic-plastic FEM analysis by optimization of the inherent strain of material.

Summary

Technology Research Association for Future Additive Manufacturing (TRAFAM) was carried out the following two projects in order to develop the innovative Additive Manufacturing systems that would meet the world's highest standards and the manufacturing technologies for high-value-added products. The schematic chart of the Next-generation industrial 3D printers project is shown in Fig.19. The main results obtained are as follows:

(A) Next-generation industrial 3D printers project

(1) TRAFAM developed the PBF type and DED type of AM prototype machines with electron beam or laser beam systems. The software for controlling AM machines and the production technology of metal powder for AM technology were developed in order to make AM machines higher performance.

(2) Morphology and temperature of a melt pool were observed and analyzed by using the electron-beam powder-bed fusion (EB-PBF) system, equipped with a high-speed camera. Based on this basic survey, the advanced monitoring system for the EB-PBF has also been designed and prototyped.

(3) The electrical and thermal properties of alloy powders used in the EB-PBF system were measured, and the effect of a surface oxide layer was analyzed in order to consider the methodology to suppress the smoke phenomena in EB-PBF system.

(4) The analysis of melting and solidification phenomenon of a melt pool by a computational fluid dynamics (CFD), solidification maps, displaying solidification microstructure as a function of solidification rate and thermal gradient at the solidification front, were determined by using a cellular automaton simulation, not experiments.

(5) Considering the melting and solidification phenomena by laser radiation, the macroscopic simulation was carried out by using the newly developed heat input model considering the different laser absorption factor values by the powder layer, solidified part, and liquid phase in the unsteady heat conduction analysis. And, by introducing the overlap ratio, it was suggested that the optimum value of energy density could be predicted.

(6) The multi-physics model in the LB-PBF system was constructed to simulate the melting and solidification phenomena at a microscopic level by using a supercomputer.

(7) The thermal elastic-plastic simulation program was developed by using the inherent strain method in order to predict the deformation of the parts fabricated by DED, LB-PBF and EB-PBF. The results analyzed by the inherent strain method coincided considerably with those of the thermal elastic-plastic FEM analysis by optimization of the inherent strain of materials.

(8) The tensile tests and fatigue tests were carried out using the specimens fabricated by PBF and DED type prototype machines. The tensile strength of the as-built and HIPed specimens was similar to that of the wrought materials. The fatigue strength of the as-built specimens was lower than that of the wrought materials, while the fatigue strength of the HIPed specimens was similar to that of the wrought materials.

(9) The obtained data have been stored in the database designed and developed in this project.

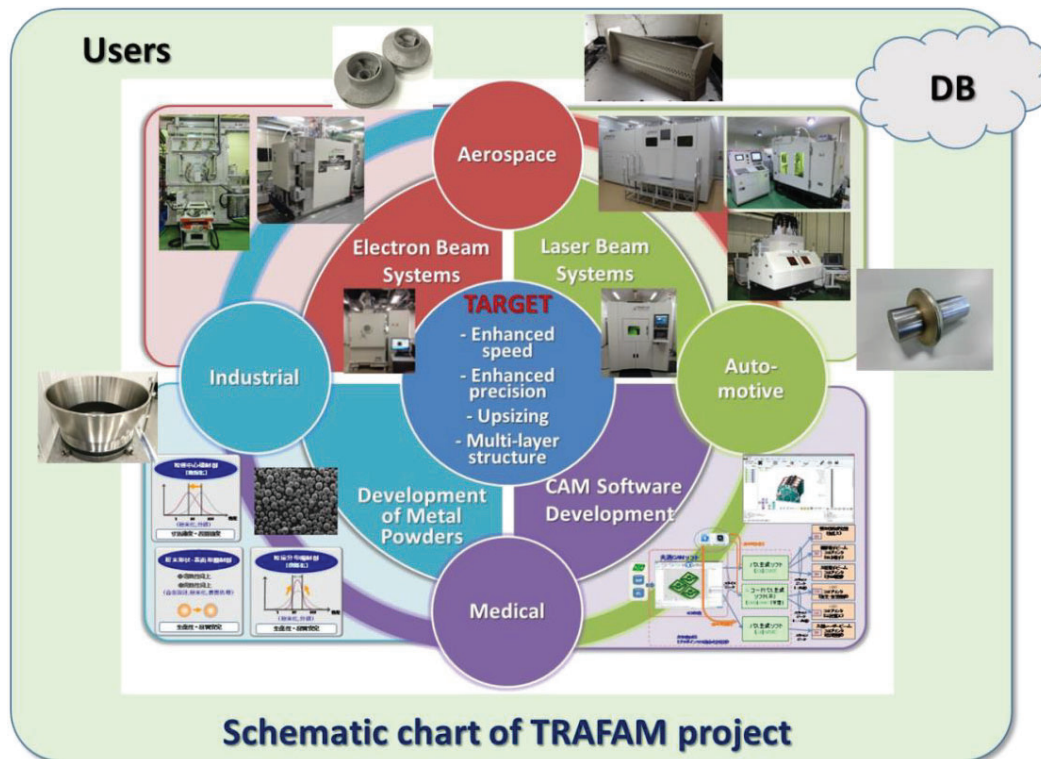


Fig.19 Schematic chart of the Next-generation industrial 3D printers project

(B) Development of 3D printing systems for sandcasting cores and molds

The large-scale AM machines and materials for sand mold, which enable us to produce the required complex molds and unified cores for metal casting were developed by CMET INC..

By FY2016, the first large AM machine with an organic binder and a coated sand was developed to achieve the desired build speed of 100000 cc/h and work size (more than 1000 x 1000 x 600 mm).

In FY2017, the non-organic binder sand mold for AM system was developed to improve environment of foundry. Sound cast parts were able to be obtained using this sand. The sand mold AM machine which can use two types of sand partially was developed. The effect of reducing casting defects by the difference of heat capacity in sand mold parts was able to be verified.

In FY2018, the largest sand mold AM machine (Fig.20) was developed and achieved the desired build speed of 100000 cc/h and work size (1800x1000x750). An example of a sand mold part is shown in Fig.21.



Fig.20 Sand mold AM machine developed by CMET

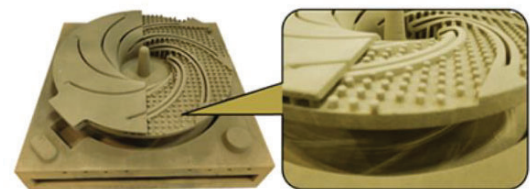


Fig.21 An example of sand mold

Acknowledgement

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