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Current Status of 3D Printer Use among Automotive Suppliers: Can 3D Printed-parts Replace Cast Parts?

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Abstract

35 years have passed since the invention of the 3D printer. In the meantime, there have been several 3D printer “movements.” Recently, individual 3D printers have become available at a lower cost and smaller size, and their use has become widespread. In the United States, emerging automakers have produced an electric vehicle by means of a 3D business printer and unveiled it at the North American Auto Show in January 2015, drawing worldwide attention. Moreover, the existing manufacturing industry has advanced the use of 3D printers. In this paper, the use of the 3D printer among automotive suppliers of Japan is analyzed. The types and characteristics of the 3D printer are explained. Although Direct Digital Manufacturing is increasingly being used in the manufacturing industry, 3D printers still play a part. The author discusses the future prospects and challenges of 3D printing based on the results discussions regarding 3D printer use with automotive suppliers.

1 Introduction

Since the introduction of NC machines throughout the manufacturing industry, digitization at the manufacturing site has been realized. Digitization of the manufacturing process design stage and advanced drawing creation of upstream processes has been performed in CAD since the 1970s.

Around 1980, the use of 3D CAD facilitated the recognition of a three-dimensional image on screen, without making a prototype. This enabled simulation, which reduced development time and costs. Linkage of CAD and CAE made it possible to implement simulations, such as structural analysis, fluid analysis on a computer, and facilitated design iterations and prototyping. These improvements reduced the trial period and costs. Production of prototypes requires a high degree of knowledge and experience. However, since the advent of the 3D printer in 1980, it became easy to make something directly based on 3D digital data. Companies may respond to a shortage of skilled technicians by using a 3D printer. The development of 3D printers led to Direct Digital Manufacturing (DDM), which utilizes digital data from design to manufacturing.

The material used by the first 3D printer in the world was a photocurable resin (such as epoxy). Then ABS, ASA, and PC came to handle such simpler materials such as wood, ceramic, and other types of metal powder. The types of 3D printers also diversified, and there grew an assortment of devices available from expensive printers for large-scale industrial purposes to cheap personal printers that could be used from a tabletop.

It is possible to make a variety of products made to order even without large-scale facilities using a 3D printer. A 3D printer can create objects no matter how complex the shape of the model if there is CAD data. Recently an electric prototype vehicle using few parts was fabricated by means of a 3D printer, and a small auto maker has manufactured a consumer car that reflects the design demanded by customers using a 3D printer, and these custom vehicles have begun to sell. The most recent applications of 3D printing technology are hot topics among emerging automobile manufacturers, and some technical papers about 3D printers have been published. However, there are few papers associated with the use of 3D printers in automobile production among assembly manufacturers and suppliers.

According to the review of the business case of Additive Manufacturing (AM) by M.J. Cotteleer, at the time of 2012, plastics or polymers accounted for approximately 81% of AM material and metals accounted for less than 6%. Complex plastic parts can be replaced by production by instead AM to traditional manufacturing methods. However, some industry watchers report "remarkable promise" in the application of AM for large structural parts in the aerospace and defense applications. Also, it points out that 3D printer of the metal powder sintered scheme using a laser or electron beam (EB) are likely to produce cost-effective for the complex shape of the component produced (Cotteleer, 2014).

K.V. Wong and A. Hernandez of the University of Miami claim as AM application, such as lightweight machines, architectural modeling and medical applications like a prosthetic socket. Especially, they point out that complex the strength of shaped parts with a hollow structure is increased by being integrally molded with AM and that the cost is reduced by shortening the process (Wong and Hernandez, 2012).

R. Miller has taken up aerospace and automotive and foundry fields as the application of the current AM. NASA is testing to produce the components of the rocket engine with 3D printer. When it becomes necessary maintenance parts Tornado fighter of Royal Air Force (RAF) by AM producing, it has made it possible to eliminate the inventory of parts. In the case of NASCAR of Hendrick Motorsports, it tests produce a prototype in 3D printer and creates such as a mirror mount which is non-essential equipment by 3D printer (Miller, 2015). Although the use of 3D printers in the foundry is the explanation about making molds and creating directly products, there is no detailed description. In this paper, it is discussed of AM in casting how to create the mold through cases of visited supplier.

Since the 3D printer to the metal material in the manufacturing industry has been popular, E. Herderick has reviewed the AM of metal. Applications of 3D printer are repair parts of the aerospace industry and medical areas such as dental implants, orthopedics. It is introduced the case of using Germany EOS's 3D printer by laser irradiation and Swedish ARCAM’s 3D printer by electron beam irradiation (Herderick, 2011). It would be discussed whether it is possible to alternate conventional casting parts to parts by AM through the company which has introduced 3D printers of both two companies.

The purpose of this paper is to consider how 3D printers are used in parts manufacturing, whether or not current use is effective, and what challenges 3D printers pose for Japanese suppliers. The information provided here was derived from the author’s interviews with Japanese suppliers.

Metal parts are one of the core functional components in the automobile industry, and it is necessary to consider whether cast parts using conventional molds can be replaced with DDM parts made by 3D printers. In addition, the purpose of this paper is to consider the implications for the process of modeling that the installation of 3D printers will have for production line utilization. However, since this paper focuses on the casting supplier, it is uncertain whether the discussion here can be generalized to other types of parts suppliers. Future surveys will consider the role of 3D printing in the design and manufacturing process of other types of suppliers. Movements associated with recent developments in 3D printer technology are overviewed in Chapter 2. Classifications of diverse types of 3D printers and the characteristics of each are described in Chapter 3. In Chapter 4, the current uses of 3D printers in the automobile industry are discussed. In Chapter 5, the author discusses how 3D printers are used and their effects on existing Japanese automotive suppliers. In addition, the results of an analysis of the current state of 3D printers among suppliers are used to draw conclusions about future prospects for 3-D printing in the automobile industry.

2 3D printer and The Maker Movement

The first 3D printer in the world was invented in 1980 by Hideo Kodama, who worked for the Nagoya Municipal Industrial Research Institute. He patented it as a "solid figure creation device." In the patent system in Japan, with request for examination after the application, it is not possible for the patent rights to be rejected. He did not do this. Instead, he published a paper on automatic 3D modeling methods with plastic in the Journal Review of Scientific Instruments of the American Institute of Physics (Kodama, 1981). Thus the “stereolithography” method became known worldwide.

Yoji Mrutani, who worked in the Technology Research Institute of Osaka Prefecture, and Chars W. Hull each have held patents on stereolithography of 3D printers since 1984. Hull then established 3D Systems, Inc. and began selling the world's first stereolithographic 3D printers in 1987. Then, other types of 3D printers (more information in the next chapter) were also developed. In the early 1990s, an industrial 3D printer, appeared, which attracted considerable attention because it used 3DCAD data to create even very difficult shapes using conventional manufacturing methods.

In around 2000 it became increasingly common to make prototypes of industrial products using 3D printers. At that time, the use of "Rapid Prototyping Equipment" was more common than 3D printers. The 3D printers created by 3Dsystem Inc. and Stratasys Inc. ranged in cost from the hundreds of thousands of US dollars to around one million US dollars. Production using 3D printers by simply changing the CAD data in the same equipment and software made it is possible to respond flexibly to customer specifications. B. Joseph Pine II, the author of "Experience Economy" and a digital manufacturer says that if the 3D printer to spread, the manufacturing sector would shift from "Mass Production" which is provides conventional single products to "Mass Customization" which is combined product making according to personal preference[1].

In the United States, it is common for individuals to approach carpentry and car repair as DIY projects. By the 1970s DIY projects included making one’s own PC, and by the 1980’s self-made music became popular. Around 2000 it became possible for individual to use 3D printers because of decreased costs and miniaturization. By introducing 3D printers in small and medium-sized enterprises, it has become possible to design and manufacture products even without large production facilities and skilled workers. In the background, there is the technology at each stage, from design to manufacturing, and it is exposed is programmed on the Internet. Additionally, a community that utilizes a 3D printer and CAD software has formed, and information is freely exchanged. Thus, the hurdle for individuals and small businesses to become manufacturers gets lower and lower. C. Anderson named this phenomenon "The Maker Movement" (Anderson, 2012). In addition, there are a growing number of places where you can use a 3D printer and experience the fun of making things even without owning a 3D printer. President Obama, in order to further promote the Maker Movement, has launched a program to expand the number of "makersspace," where you can easily use new technology such as 3D printers in thousands of schools in the United States beginning in 2012. The purpose of these workshops is not the development and re-education of factory workers, but rather the development of innovators in the new generation of system designers in the manufacturing industry. In the United States, it can be seen that they are aiming for a return to reinvigorate the manufacturing industry by incorporating computers into the experience of making things at the grassroots level[2].

From around 2010 in Japan, the price of 3D printers became cheaper and, and the devices grew smaller. Individuals had easy access to the technology. Even without owning a 3D printer and in the absence of US-style workshops, it is possible for individuals to use service companies that provide access to 3D printers. In particular, services for the individual who cannot buy an expensive high-performance 3D printer can make products for him if he sends the 3D data to a 3D service company over the network. Even without requests designed for industrial designers, it is not necessary to commission a factory because products are designed on the screen, and it has become possible create significant output in a short time by means of a 3D printer.

If individuals are using 3D printers in both the United States in Japan, DDM from design to manufacturing has become easy. Also the 3D printer-related community through a network provides tremendous support, so the individual or small group can look for suppliers of materials and parts; it is possible to deploy a new business drawing on the community to learn about the issues surrounding 3D printer hardware and software. The products produced by these new businesses can be marketed throughout the world by means of the Internet, without need of a distribution network.

3 3D printer types and characteristics

The following steps describe the use of a 3D printer, from the design stage up to molding:

- Design (illustration, design diagrams, 2DCAD)
- Create 3D data such as 3DCAD and 3DCG
- Convert to data format for 3D printers such as STL
- Prepare output such as position of the object, the direction of the change, etc.

- Create slice data for 3D printers and stack
- Output from 3D printer (modeling)
- Complete by removing unnecessary portions such as foundation and support

The kind of 3D printers is various, but in this paper they are classified according to lamination method and types of materials used in production.

(1) Stereolithography (SLA) method

Kodama Hideo created the world's first 3D printer using this method. Photocurable resin liquid is irradiated with laser to shape while curing. Photocurable liquid polymer is poured into a tank and is cured by irradiating it with a laser beam on the surface of the resin. By lowering (or rising) the tank, the surface of the next new resin is cured. The three-dimensional object is shaped by repeating this process. Japan manufacturers are a field that specializes in 3D printing has many patents on equipment and related technology. In addition, they have the accumulation of knowledge and experience about the resin material. Lamination pitch is 0.15mm from 0.05mm. Since the light-curable liquid polymer is harmful to humans, care must be taken in handling. It is not suitable for tableware.

(2) Material injection method

In this method, thermoplastic resin is dissolved from a nozzle by heat and a method of molding by injecting the material directly a nozzle for molding by injection of filamentous material.

(a) Fused Filament Fabrication (FFF) method

A resin such as ABS, PC, PC-ABS and PPSU is pushed out from the nozzle of the heater. When using the support material, it is a dedicated nozzle. Since the stacking pitch is thicker, from 0.1mm to 0.3mm, it is not suitable for high-precision machining. However, this method has been extensively used in personal and industrial contexts because material handling is easy. This method was developed in the late 1980s by the United States Stratasys Inc. Scott clamp, Fused Deposition Modeling (FDM) are registered trademarks for this method. Other manufacturers have called this the Fused Filament Fabrication (FFF) method, but the term FDM is commonly used.

(b) An inkjet method

Photocurable resin is ejected from a nozzle, and then it is laminated and cured by irradiation with an ultraviolet lamp. Stacking pitch is from 0.015mm to 0.03mm, so it is capable of very accurate modeling. The surface is smooth compared to FFF. Acrylic resins utilized in this manner are friable, leaving no sticky residue compared to ABS. However, by adjusting the chemical composition of the resin with ABSlike, PPlike, since it is similar to rubberlike materials, it is possible to evaluate the material functions. There is also an extract type that ejects sand from a nozzle. The sand is called furan self-hardening sand. After lamination ends, it cures in about 3 hours.

(3) Powder Bed Fusion (PBF) method

Selective laser sintering (SLS) was developed and patented by Dr. Carl Deckard and his academic adviser, Dr. Joe Beaman at the University of Texas at Austin in the mid-1980s[3]. Then, a method of sintering a powder using an electron beam was developed. The type of material expanded to include metals, ceramics, and powder and nylon resin. Sintering by means of a laser came to be called Laser Beam Melting (LBM). Sintering by means of an electron beam became known as Electron Beam Melting (EBM). In addition, ASTM gave the general name Powder Bed Fusion (PBF) for these comprehensive names. In the case of nylon resin, the molded product is flexible. The finish cannot be as fine modeling as the powdery surface produced by SLA. Unless the shape is complicated shape, there is no need to consider the support material as compared to other methods because the powder takes the place of the support material. With the use of ceramics, it is possible to modeling of dishes and cups. The German EOS Company accounts for about 70% of global use of PBF 3D printers using a metal powder. The Swedish Arcam Company accounts for about 20%.

(4) Powder Fixing method

An easy and inexpensive material such as gypsum and ceramic powder are a method to solidify materials by bonding with resin. In recent models, with ink nozzles attached, it is possible to specify the coloring of the solid in 3D CAD or 3D CG in synchronization with the shaping of the body. Since the shaped article is only hardened with adhesive, and brittle, it is easily damaged by shock. What has been shaped with ceramic powder bakes in oven and can be used as cups or dishes. The 3D printer to be introduced in Chapter 5 uses an ink jet and powder sintering method.

Interestingly, 3D Printing is accomplished by adding layers of material and by repeating the lamination process. Conventional processing was done by subtraction of mass by means of a cutting instrument. In 2009, ASTM International (formerly American Society for Testing and Materials: ASTM) held a conference and installed the F42 committee. This committee termed the method of adding materials and repeating the lamination process Additive Manufacturing (AM). Features of Additive Manufacturing are that even without the mold, a material product can be produced directly. Also it is possible to freely model and create and cut hollow structures out of metal, which was difficult before. As a result, 3D printers are now one of the major components for implementing DDM.

4 Usage of 3D printer in the automotive industry

At the Toyota Motor Corp International Auto Show, which was held in New York in April 2014, the exhibition of scaled-down model concept car FT-1 that was produced in 3D printer was a hot topic. MakerBot, which is an American 3D printer manufacturer, produced this model[4].

Toyota acquired the patent, which is a shaped model with a slit uncured vertical stack of stereolithography and a secondary cured slit after shaping the model, using the SLA method in 1996. The company patented a laser light irradiation type of manufacturing molding apparatus in 1996. They also obtained a patent for the powder sintering method, the spraying method, and the apparatus for layered manufacturing in 1997[5]. Toyota has continued to conduct research and development for lamination methods and holds a large number of patents. Toyota currently uses 3D printers to make prototypes of interior trim or to create engines of a transparent material to test that engine oil is normal, and whether the flow is efficient. However, the robust use of 3D printers to create prototypes of auto body parts has not yet to be realized[6].

Start-ups such as the following, as well than the existing OEM in the United States, are working on production of passenger cars using 3D printers.

Urbee, a prototype of the first fully functioning 3D-printed automobile, was presented to the world at the Canadian TEDx conference in 2011. In 2013, it was announced that the Urbee2 would feature sophisticated futuristic design. This car was modeling with ABS plastic with 3D printer using the FFF method[7].

Local Motors in North America International Auto Show 2015, which kicked off in Detroit in January of 2015, announced the electric car "Strati," a two-seater that was fabricated using a 3D printer. The car was actually printed and driven at the venue, and video of this created a considerable splash. The company was created by Jay Rogers and Jeff Jones in 2007 with the aim of making a car on the web. When launching a site about car design and engineering, a community of advocates began to form. In 2008, by specifying the design of the motif of the Mustang fighter, they held a design contest on the web, producing a "Rally Fighter" of the original winning design. This was the first passenger car in the world developed through open source. The company after the establishment in Boston was transferred to headquarters in Phoenix, Arizona. Manufacturing facilities using the 3D printer is in Knoxville, Tennessee. Since the company inception technology is not related and no large 3D printer in the company, Oak Ridge National Laboratory has both. The Laboratory belongs to United States Department of Energy (DOE). Local Mortars announced the electric car "Strati" made by the world's first fully 3D printer in January 2015. This is the world’s first 3-D printed vehicle build using DMM, they say. Michele Anoe's design won the top prize in the open community contest "3D printing car design challenge" has become a group[8].

Local Motors plant has not production line. It makes cars with 3D printers and CNC, etc. Local Motors’ facilities are considered a micro-factory and laboratory. Right now there are micro-factories in Phoenix and Las Vegas, but there should be micro-factories in four or five other places within the next 12 years[9]. In the manufacture of vehicles by Local Motors, the customer will participate in the community of design and engineering. If the customer is not a member of these communities, he will continue to determine the specifications while maintaining contact with members of the community. In the United States, the end user becomes involved in production, it falls outside the parameters of product liability law and consumer protection laws. However, it is approved to run on public roads by a simple procedure as described above.

In contrast, since 3-D printed cars are in Japan must meet requirements similar to those of OEM in terms of procedures and registration for traveling, the user of 3-D cars in Japan face significant cost and a long waiting period before being able to drive on public roads. Therefore, start-ups in Japan similar to Urbee and Local Motors have not yet appeared. Therefore, we should consider the use of 3D printers among existing suppliers in the next chapter.

5 3D printer uses among automotive suppliers in Japan

In the 2000s, 3D printers began to be sold at a reasonable price in Japan, so it has become popular and has been introduced in the design sector of large companies and small and medium-sized enterprises. Recently the author had the chance to interview 3D printer manufacturers and casting suppliers that use 3D printers. Information from these interviews is analyzed to determine the current state of 3D printer use among Japanese automotive suppliers.

(1) Roland DG Corporation[10]

Roland DG Corporation was separated from Roland Corporation, which is a manufacturer located in Hamamatsu, Japan to manufacture and sell synth cider and electronic musical instruments such as electronic pianos in 1981. The company has been manufacturing and selling large printers for business, cutting plotter. Roland DG developed these technologies and has years of accumulated knowledge of CAD and CAM. It began the manufacture and sale of a desk-top type 3D printer and Milling Machine a few years ago. Since the purchase price of these two items were about $10,000 or less, sales to department units of companies was extended.

Traditionally, if the component designer tries to check the finished product at the design stage, he would imagine the finished product and look at the 3D data screen, or he would create a mock-up from 3D data and would take it in hand. Traditional mock-up production procedure is as follows: "Review mock-up" (a study stage to see if it is necessary to quickly manufacture), "the concept mock-up" (for the concept of approval), "final mock-up" (for confirmation of the final appearance), and "over-the-counter mock-up "(for a sample to the end user). Since the designers desire to check and remake quickly many times in the middle of the mock-up is strong, it took time and cost to outsource the mock-up.

The SLA method 3D printer ARM-10 provided by Roland DG Corporation stacks the product of smartphone-sized thickness (5cm) in about 8 hours. When a designer activates the 3D printer upon leaving the company, the product will be completed upon arrival at the company the next morning. This usability is evaluated highly by the user. The material used by the company's low-priced desktop type of SLA method 3D printer is a light-curing resin. If a user wants to use another material, such as a prototype wood, wax, ABS etc., he could use SRM-20, which is a low-priced desktop type milling machine. The combination of 3D printers and tabletop milling machines has been introduced in the design department of automobile manufacturers and suppliers of Japan. Next, let us consider the case of KOIWAI Co., Ltd., which manufactures automotive parts using a 3D printer.

(2) KOIWAI Co., Ltd[11]

KOIWAI Co., Ltd is founded in 1973 and is engaged in the manufacture and sale of casting parts. It is common that casting industry companies inherit traditional technology, but KOIWAI began the digitization of making things using the 3D CAD in 1998. Then, it used a 3D stacked sand casting method in 2007, and has been working on 3D metal powder sintering lamination method for the production of metal parts directly from CAD data since 2012. Currently, there are four plants in Japan and one plant in Bangalore State, India. The configuration of the 2013 fiscal year sales of prototype casting parts is 63.5%, mass production casting parts is 35%, other (metal powder 1%, non-destructive inspection 0.5%). These numbers are from fiscal 2013.

(a) Main products

Mass production castings of automotive parts are for super-turbocharger and turbocharger vehicles. These materials are AC4C (Al-Si-Mg-based materials of aluminum castings). The target for superchargers is 2,000 sets per month, and 1,000 sets per month for turbo chargers. In addition, engine-related parts of watercraft and marine vehicles (cylinder head, cylinder block, transmission case, the intake manifold, and exhaust manifold) for cars, trucks, construction machinery, and front suspension are made. It has also been manufacturing rear suspension. AC4C have manufactured 18 of these materials, up to 3,000 per month. Its competitive point is that it is possible to launch mass production of components such as complex-shaped parts and thin-walled machined parts and double structure tubes from the 3D prototype in a short time.

Prototype castings of automotive parts for vehicle superchargers are the main product. It received orders for turbochargers from Honeywell Japan, IHI Turbo, Mitsubishi Heavy Industries, and BorgWarner Turbo Emissions. In addition, a prototype of automobile parts and research parts has also been ordered. These are the production of casting parts in 3D lamination sand mold for casting. That is, first a sand mold is built with a 3D printer, and then a casting is made after pouring a material such as aluminum, cast iron, or cast steel, etc.

(b) Creating a casting sand mold using a 3D printer

In general, casting by sand mold production using the conventional wooden material requires 9 stages (casting measure 3D modeling, wooden material processing, model processing, model finishing, frame-wood plate manufacturing, assembling, finishing, sand mold molding, and casting completed). But if a sand mold is built by a 3D printer requires only three stages (casting measure 3D modeling, laminating sand mold molding using a 3D printer, casting complete). When producing a sand mold by wood it took ten days because manufacturing had to be outsourced. With a 3D printer, the process was shortened to two days. The entire construction period in the use of 3D printer on average has been reduced by two thirds. Also, 3D printers can make a sand mold of complicated shape that is far more difficult to make with wood. KOIWAI is making a sand mold using two different types of 3D printer as the mechanism. Below we confirm this case study in detail.

(i) Selective Laser Sintering

EOSINT-S750 is a system that EOS (Electronic Optical Systems GmbH) in Munich developed. It creates a stacked molding of sand directly without the use of wood. It is laminated by irradiating the carbon dioxide gas laser corresponding to the expanded slice data in the material sand sheets of the main mold and core sand mold casting from the 3D data, and shaping. Turbochargers are cast using a sand mold created by 3D printers. The company installed this model in 2007. If a sand mold is created directly by the 3D printer, it can shorten the time from design to manufacturing.

(ii) Ink-jet printing casting sand mold lamination

KOIWAI installed S-Max (ExOne Co., modeling size 1800 × 1000 × 700) in 2012 in order to build a larger castings sand mold. It creates not only large castings products; it is also available to mold various kinds of small-quantity models of the foundry sand type of small items, since the company has created 40 species close to prototype per month on average. Also, it is possible to correspond to mass production and be designed to cast sand molds of the same design smaller. When self-hardening sand is blown from the nozzle according to the design data such as 3DCAD it is cured about 3 hours after lamination.

(c) Creating the metal parts with a 3D printer

Arcam's Arcanm A2X made in Sweden was installed in 2012. The maximum laminate is 200x200x350mm. Those from 55 cm2 to the size of 80cm2 can be stacked in one hour. For sheets of titanium, cobalt crumb, electron beam scanning is performed on the metal powder Inconel; it dissolves the metal powder and kinetic energy is converted into heat when electrons are irradiated to a design pattern that has been converted from the CAD data. KOIWAI has installed the EOS's EOS M280 and CONCEPT LASER's CONCEPT LASER M2 by a laser beam irradiation, not by an electron beam irradiation. Steps from design to manufacturing are as follows: 3D design, STL-file conversion, and slice file conversion, data transfer to the laminating apparatus, stacked processing (manufacturing), and the completion of the metal parts. Main automotive parts such as the gearbox, manifold (exhaust manifold exhaust manifold, such as intake manifold manifold), and prototypes of the engine-related casting parts are produced.

6 Discussions

We should discuss the following to further deepen our understanding of casting sand molding the printer and the metal powder stacked printer from the case studies of 3D printer among automotive suppliers in Japan.

(1) Casting sand mold modeling 3D printer

(a) Installation background

The requirement for higher accuracy of casting from customers such as automobile manufacturers has become harder, and short-term delivery is demanded. However, an increasing number of companies which built wooden traditional foundry sand molds are closing because there is a lack of senior engineers passing knowledge on to successors. Outsourcing foundry molds using wood is time consuming and costly. Therefore, modeling of the casting of the final product that can be competitive, and differentiation is difficult. In the case of KOIWAI, the company's management strategy attempted to reimagine casting mold production and to differentiate it from the competition with the introduction of the 3D printer. Installation of 3D printers has changed the image of Japan's casting industry from hard, dirty and dangerous work to the cutting-edge technology. During a visit to the KOIWAI factory, the author confirmed the dominance young people in the workplace.

(b) Introduction Effect

In the case of castings sand mold using wood, the work of a skilled person is necessary when the sand mold is created. Also, when the casting is completed, it is also necessary to successfully remove the wood mold. By using a 3D printer, these tasks can be eliminated. In the case of KOIWAI, the entire construction period is reduced to between one tenth and one third on average. When using a wooden mold, a sand mold cannot be created with a fine and complex shape; there is a restriction in the final product design. However, when using a 3D printer a direct casting sand mold is designed by CAD, and a calculation can be performed to test pre-strength or interference in conjunction with the CAE analysis. Thus, the degree of freedom in product design increases. Because it is designed in CAD, there is high accuracy of dimensions, and complexity correspondent is facilitated to such a thin thickness of the shape or a tube. It can directly cast a sand mold based on data.

(c) Issues

There are the following constraints related to the use of 3D printer devices: the user has less freedom of the time in use. The sand diameter and the shape are specified. Sand mold thickness and shaping speed are designated conditions determined by the molding range. Currently, much of the business for 3D printers for foreign-made service system is insufficient. Manufacturers of genuine products may be limited by the availability of consumables (sand, binder, etc.). Moreover, materials are expensive. It is not possible to reuse the sand. The 3D printer manufacturer's management strategy is similar to that of computer printer manufacturers. They make a profit on consumables ink cartridges. Because 3D printer hardware is expensive equipment—often in excess of \$ 1 million—small and medium-sized enterprises cannot buy easily. In the future, this state of affairs will continue until the 3D printer manufacturers and materials manufacturers of Japan are forced through competition to make their prices more reasonable.

(2) Metal powder sintering stacked 3D printers

Metal powder sintering stacked 3D printers build a metal shaped object directly by dissolving the metal powder at a high temperature. Since a mold is not necessary, shaping time compared with that of castings that use a mold is drastically reduced. It is possible to realize lower costs. However, the laminated metal parts of 200mm * 200mm * 200mm size by sintering metal powder can take from 20 hours to 30 hours. The current metal powder sintering laminated printer is suited to the production of just a few prototypes and special orders. It may be unsuitable for production of mass-produced parts. Metal powder sintering laminated printers have different configuration characteristics and use an electron beam to dissolve the metal powder. A laser can smooth the surface and edges of metal shaped objects. The electron beam can have a high degree of freedom in designing the external shape of the article.

Metal powder sintering laminated printers have been used for business since the beginning of 2000, but there is a problem whereby the edge of the finished product is bent, presenting a challenge to the lamination method. The solution is placement of support material and/or the removal of the residual stress. Furthermore, it is also necessary to verify that the density of the finished component is 100%. However, international standards have yet to be established, and there are no uniform inspection methods and inspection system for residual stress and density for metal products made by metal powder sintering. The agency has discussed the enactment of international standards, such as ISO and ASTN International, but these discussions have not yet concluded. If there are international standards and established inspection methods, metal parts shaped by metal powder sintering laminated printers will be used with greater confidence. KOIWAI has joined the debate by participating in the working group of standardization related to ISO and ASTN International regarding metal powder sintering laminated printers.

7 Conclusions

For the question as to whether alternative casting parts created by 3D printers can replace traditionally casted parts, the answer is a tentative "Yes". KOIWAI has demonstrated that it is possible to create a sand mold by means of a 3D printer to reduce the steps previously necessary for traditional casting and use it for mass production. That is, a hybrid of the use of the traditional methods and 3D printers has been successful. The current status of 3D printers in the production of metal parts in DDM is that it is available primarily for the creation of prototypes, and less so for mass-produced parts. One of the reasons is that customers such as OEM do not require metal parts produced via DDM at the moment. However, it can be pointed out that evaluation criterion and the evaluation method of the residual stress and the density of components shaped by 3D printers has not yet been established. Progress toward the enactment of national and international standards is currently being discussed by ISO and ASTM International, but is likely to take some time. We await the results.

There are several 3D printer manufacturers In Japan, as shown in Table 1. Japanese users have a desire for domestic 3D printers on par with the high-performance and high-speed 3D printers made in Germany and Sweden. Furthermore, currently, material is limited to 3D manufacturer specifics, so the cost is high. Cost reduction of material is required for the future spread of 3D printer use in Japan.

Table1. Japanese 3D printer maker

Lamination method	Typical company
SLA	CMET, D-MEC
FFF, Inkjet	Hotproceed, KYEENCE
PBF	Matsuura Machinery, ASPECT

Source: The author.

Since the mechanism of current 3D printers cannot be produce output quickly, the best current use of these printers is in the building of prototypes of a single item. However, at the present time they are not suitable for mass production. As computer technology continues to enhance the processing capacity of a single CPU to multiple CPUs, 3D printer also requires innovations for increased output to accelerate and multiply processing speed.

The realization of 3D printers’ full potential in DDM is likely to bring innovation to both the process product of the manufacturing industry. Already design flexibility has been increased because designers can confirm in the early stages of design objects laminated by a 3D printer. Even if there are complex shapes and interfering parts that are difficult to verify in 3D CAD, 3D printers allow for the modeling of actual objects. This makes it possible to reduce production time and costs when compared with making a conventional mold.

The shape that must be constructed via conventional casting can be integrally molded by 3D printer, and this is the great innovation of 3D printers. Strength is increased, and reduction of molding time and costs can be realized. Even in cases where production of a single item is the goal, 3D printers can reduce production time and costs.

In the future, it will be possible to make products in DDM directly from data produced at the design stage by use of common software at the manufacturing stage. We can expect that data compatibility will increase in the future. In order to ensure independence from the OEM, suppliers may accumulate proprietary 3D printing technology to produce parts from the 3D data. From the interviews with the author regarding metal parts, it is clear that casting suppliers have rich experience and technological know-how of heat treatment, so they can apply appropriate treatment and set optimal conditions for melting the metal of sintered powder metal parts by means of 3D printers. It also can be a good treatment for post-processing of molded products by 3D printer. This is a major element that companies can use for differentiation.

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Note

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[1] B. Joseph Pine II insists that "Mass Production" shifts to "Mass Customization". He is a co-author of *The Experience Economy: Work Is Theater & Every Business a Stage*, 1999, Harvard Business School Pres, *Authenticity: What Consumers Really Want*, 2007, Harvard Business School Press and *Infinite Possibility: Creating Customer Value on the Digital Frontier*, 2011, Berrett-Koehler Publishers.

[2] Anderson, 2012,pp.18-19

[3] Selective Laser Sintering, Birth of an Industry, Mechanical Engineering, The University of Texas at Austin
(http://www.me.utexas.edu/news/2012/0712_sls_history.php)

[4] MakerBot Revs Up Toyota’s Presence at New York International Auto Show with 3D Printed FT-1 Concept Car
(http://www.businesswire.com/news/home/20140425005834/en/MakerBot-Revs-Toyota%E2%80%99s-Presence-York-International-Auto#.VUnFAI7tlBc)

[5] *Rapid Prototyping Technology*, National Center for Industry Property Information and Training (INPIT). This document is printed in Japanese. 『ラピッドプロトタイピング技術』独立行政法人　工業所有権情報・研修館

[6] Y. Satoh reported that 3D printer the person in charge of the description of the Toyota Motor Corporation had a speech in the "3D printer utilization seminar" at Yamagata Prefecture, advanced technical training Development Center. This document is printed in Japanese.

(http://www.nagai-th.ed.jp/siguma/h25/yosirou.pdf)

[7] Urbee is in reference from article of Joslin (2010) and Urbee 2 is from George (2013).

[8] Sources are Japanese journalist Momota (2015) and American journalist Korzeniewski, (2015).

[9] Local Motors, Microfactory Features. (https://localmotors.com/microfactory/)

[10] The author joined the conference of 3D printer user's case study at Tokyo office of Roland DG Corporation and interviewed the person in charge on Feb. 2015.

[11] Source is internal documents and the author's interview to the person in charge at the head office of KOIWAI on March 2015.

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