Recent application of StereoLithograpy and overview of rapid model fabrication technology

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ABSTRACT

With the advance of Automization, a computer-aided design/ computer-aided manufacturing (CAD/CAM) has become basic tools in industry. Recently a new technology called StereoLithography makes it possible to produce solid objects more rapidly from CAD data than conventional machine tools.

StereoLithography slices 3D model into many thin layers, a laser beam scanned by computer controlled mirror solidifies the sliced pattern on a photosensitive resin, then solidified pattern is lowered in the resin so that it can stack new layer, and the process is repeated layer by layer.

This paper describes recent applications of the StereoLithography model. There are also many related fabrication methods, this paper summarizes the differences and characteristics of other fabrication technologies.

The subjects of these methods are also discussed regarding current requirement to the models.

1.Trend of the manufacturing technology using with StereoLithography

Stereolithography apparatus (SLA) has been already sold by several companies in Japan and in United States, and has been used to build the mock-up of electric products and so on. Recently this SLA model has been studied not only to use a test model but also to make a die adding a backup material.

The resin which is used for SLA has a temperature decomposition characteristic which is not suitable for burnout model. For this reason, the development of the resin suitable for investment casting has been studied by J. J. Krajewski and E. J. Murphy, Desoto Inc.[1].

The fabrication of die is studied which the SLA model is coated with alloy from 3 to 4mm in thickness by the spray metal tooling and is backed up with the epoxy resin enforced with Aluminum[2].

2. Overview of rapid model making technologies and their features

The fabrication technique for three dimensional model has been proposed and experimented with many kind of methods and some of which are on the market.

(A) The methods which use photopolymer

In 1974, J. D. Lewis, Battelle Columbus laboratory, developed the photo chemical machining (PCM)[3]. It uses photosensitive resin which is polymerized only when the two wavelength of lights are exposed, and computer controlled mirrors are used for the two laser beams to move freely their cross section in a vat.

In 1981, H. Kodama, Nagoya Municipal Industrial Research Institute in Japan, made three-dimensional models using with photo hardening polymer and several kind of mask films. And from the result he proposed new three-dimensional Display for the three-dimensional information[4].

In 1984, T. Otani, Nihon university in Japan, applied photopolymer to the fabrication of a relief plate casting[5]. In 1986, Efrem V. Fudim also made parts using mask film[6].

In 1985 Y. Marutani patented the fabrication of the three dimensional model in Japan[7]. The UV laser beam moved by XY stage hardens the surface of photo polymer in a vat to the slice shapes of models and the layer is lowered in the resin to make a new layer, and finally the complete model is made in the vat. Almost the same time, W. Hull, 3D systems Inc., patented in U.S.A[8]. The apparatus for production of three-dimensional models (SLA) is the same principle as Marutani's.

The above method has the limitation of a model size owing to the vat volume and needs waiting time between layers to change new liquid surface into flat, therefore the author proposed continuous spot transfer method (CST)[9]. This method concentrates photoresins and UV beams into a small region and creates the three dimensional models transferring surface shape using with guide plate, and coned shapes were made as experiments.

(B) The methods which use other materials

Aiming at the fabrication of artificial organs, M.Hori, Waseda university, made models similar to a Y shaped blood vessel and a valve of heart using with Silicone hardened at room temperature[10].

In 1985, H. Nakazawa, Waseda university, proposed laser rheology processing (LRP)[11] which used creamy material mixed with powder metal and liquid binder and the material was melt by CO_2 laser, and finally formed into three dimensional objects.

T. E. Doyle makes three dimensional shapes using with arc welding and Robot controls [12](SMT: Shape Melting Technology).

DTM corporation proposes selective laser sintering (SLS)[13] which powder metal layer is leveled to be flat by leveling drum, and sintered by laser beam and is stacked layer by layer.

In 1990, E. Sachs et al., MIT, proposed three dimensional printing (TDP) which used ink jet nozzle instead of laser, and bound powder metal selectively by ink-jet printing of a binder material, and parts were created by a layered printing process[14].

In 1989, M. Anzai and T. Nakagawa, Tokyo university, created cylindrical model using with plasma powder melting method (PPM) which powder metal was melted into bead by plasma torch and a shape was formed by moving the bead using with robot arm[15].

Perception systems Inc. proposed the ballistic particle manufacturing process(BPM)[16] which particles of materials were deposited onto a substrate to construct three dimensional structure.

In 1979, M. Kunieda, Tokyo university of agriculture & technology, and T. Nakagawa, Tokyo university, made laminated die as experiments and realized deep drawing of metal sheet[17][18].

In 1988, M. Fagin, Hydronetics, proposed laminated object manufacturing (LOM)[19] which the periphery of the cross section of object was cut from a sheet material by laser and incrementally stacked on the old one, and the process was realized using sheet materials such as plastic films, paper and metal foils.

3. Comparison of methods and their characteristics

The above mentioned methods are summarized in Table 1-A to 1-D.

In the table, "Material" means the material mainly used with the method, and "Phase change" means the change state of a material from the beginning to the end of the process. The frequency of the change can be useful to estimate the accuracy of the final products.

"Mechanical elements" lists the minimal elements to realize its method. Some of the apparatus in commercial use add elements for the higher precision, but it is not mentioned here.

"Necessary control technique" lists the minimal control technique to move mechanical elements and make three dimensional object.

Although "The main feature" and "The problem" are usually not mentioned in the references, the author lists them considered to be obvious.

"Load of additional finish" means the necessary load to finish models fabricated by the method into the required tolerance. The easier polymerized material is used, the harder the metal material is used.

Although "The necessary technique for high accuracy and for high processing speed" is not mentioned in the references, the author's point of view is listed.

Phase changes usually result in volume changes and affect the shape accuracy, therefore it is desirable to minimize the phase changes.

And the more mechanical movements are used, and the more the technical tasks increase.

4. Discussion

As mentioned above, there are many kind of proposed methods concerning the rapid three dimensional fabrication.

Each of them has its merits and demerits, but at present the improvement of the shape accuracy is the main concern. The reasons of low accuracy are based on the materials and the principles of fabrication.

Concerning the materials, it is necessary to develop the technique to equalize the characteristics of material in the whole parts of the created object, and also to investigate the theoretical explanation of the material behavior which is valuable to get the direction of the material improvement.

As for the principle of the fabrication, it is necessary to find out new method which the discrete error caused by the object division for creation does not exceed the required error.

If these problems are solved and the system can endure the practical use, the method which has simple hardware and operation will be widely spread.

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Table 1-A. The Characteristics of rapid model fabrication methods

Method	SLA	CST	MM	PCM
material	photoresin	photoresin	photoresin	photoresin
phase change	liquid->solid	liquid->solid	liquid->solid	liquid->solid
mechanical elements	galvanomirror. XY stage+Z stage. polygon mirror+ Z stage	XY stage+Zstage+ tube pump	Z stage+ Film carrier	galvanomirror
necessary control technology	XY scanning	XY scanning. synchronization of material supply and scanning	mask production and interval transfer	XY scanning beam focusing
The main feature	simple hardware	possibility of large model	simple hardware	no moving parts in a vat
The problem	size limitation for a vat. inconsistency of high accuracy and high speed.	synchronization of material supply and scanning.	need many masks	development of ideal resin
Load of additional finish	small (finish of plastics)	small	small	small
necessary technology for high accuracy	thin layer. low shrinkage resin.	thin layer. low shrinkage resin. deformation of guide plate.	thin layer. low shrinkage resin.	low diffraction resin. resin activating only at cross section.
necessary technology for high speed	high power laser. high sensitive resin.	high power laser. high sensitive resin. synchronization of controls	high power source. high sensitive resin.	high sensitive resin.

Table 1-B. (Continues)

Method	MAO	LRP	SMT
material	cold hardening silicone	powder material+ liquid binder	welding rod
phase change	viscos fluid ->solid	viscos fluid ->solid	solid-> liquid->solid
mechanical elements	XYZ stage+ resin dispenser.	XYZ stage+ material supply pump.	Robot arm+ welding rod carrier
necessary control technology	XYZ scanning Inverval constant quantity discharge	XYZ scanning. synchronization of material supply and scanning	syncronization of material supply and scanning
The main feature	available for elastic model	no limits of alloy material	inheritance of welding technology
The problem	discharge control. slow hardening.	control of melting shape	control of melting shape
Load of additional finish	large (finish of rubber)	large (finish of metal)	large
necessary technology for high accuracy	thin layer. control of constant quantity discharge.	control of melting shape.	control of melting shape.
necessary technology for high speed	fast hardening synchronization of cotrols.	high power laser. area.	heat supply at welding

Table 1-C. (Continues)

Method	SLS	TDP	PPM	BPM
material	powder	powder	powder metal	powder
phase change	solid-> liquid->solid	solid-> viscos fluid	solid-> liquid->solid	solid-> liquid->solid
mechanical elements	galvanomirror+ Z stage+ leveling drum. Z stage	ink jet nozzle XY stage+Zstage	robot arm+ material supply pump.	XYZ stage. abZ stage.
necessary control technology	XY scanning synchronization	XY scanning. constant quantity of material supply and scanning	XYZ scanning. control of spray supply of slurry	XYZ scanning diffusion density.
The main feature	no limits of alloy material	no heat problem	no limits of alloy material	no limits of alloy material
The problem	heat diffusion	control of material supply. capillary action	control of melting material	control of spray diffusion density
Load of additional finish	large (finish of metal)	small	large	large
necessary technology for high accuracy	thin layer. heat diffusion of material and radiation.	thin layer. high resolution of nozzle	control of melting shape	synchronization of spray and scanning.
necessary technology for high speed	high power laser. scanning.	sychronization of nozzle and area	heat supply at melting scanning.	sychronization of nozzle and

Table 1-D. (Continues)

Method	LDD	LOM
material	metal plate	film sheet
phase change	none	none
mechanical elements	XY stage	XY stage+Z stage+ Film carrier
necessary control technology	XY scanning	XY scanning+ sheet transfer
The main feature	rapid layer fabrication	rapid layer fabrication
The problem	thick layer need manpower for assembling	removal of unused material
Load of additional finish	large (finish of metal)	small
necessary technology for high accuracy	thin plate.	thin sheet.
necessary technology for high speed	high power laser.	high power laser.

Stero-Lithography Apparatus (SLA)
Continuous Spot Transfer method (CST)
Mask Method (MM)*
Photo Chemical Machining (PCM)
Machining for Artificial Organ (MAO)*
Laser Rheology Processing (LRP)
Shape Melting Technology (SMT)
Selective Laser Sintering process (SLS)
Three Dimensional Printing (TDM)
Plasma Powder Melting method (PPM)
Ballistic Particle Manufacturing (BPM)
Laminated Die for Drawing (LDD)*
Laminated Object Manufacturing (LOM)

These methods marked * have no special naming in the references, so this naming is only used here to discriminate each method.