Recent Progress of Photo-Resin for Rapid Prototyping, "Resin for Stereolithography"

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Introduction

A main goal for manufacturing systems is to shorten lead-time for the development of new products. An important challenge is to make sound decisions at early stages of product development where committed costs are low which leads us to obtain a lower total cost. This could mean that incurred costs are higher in the beginning where more work has to be done in terms of learning the market, developing the product and the production system. An important feature is to avoid changes at later stages where the incurred costs are high. The stereolithography using photo curable liquid resin is important for the manufacturing. The technology based on the stereolithography has been widely accepted due to the phenomena of spreading "Information Technology (IT)" and three-dimensional computer aided design (3D CAD) system. The stereolithography technique has become very popular in the field of automotive, home-electronics industries. In this paper the photo curable liquid resins for the stereolithography system are reviewed.

History of the stereolithography

Principle technology of the stereolithography was firstly reported by Japanese researcher, H. Kodama in 1981, and improved by C. Hull of UVP (3D Systems Inc. at present) in USA and Dr. Y. Marutani of Technology Research Institute of Osaka Prefecture of Japan (Prof. of Osaka Sangyo Univ. at present) from 1984 to 1985. In 1987, 3D Systems Inc. shipped the first commercialized system of the stereolithography called “SLA-1”; it was paid much attention because of its novelty. In Japan, C-MET Inc. was established by Mitsubishi Corporation to produce the machine developed by Dr. Marutani, and the "SOUP system" was put into the market in 1988.

Principle of the stereolithography

The stereolithography apparatus accepts a specific format (STL file) translated from solid 3D

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CAD data, and "slices" it into two-dimensional cross sections for laser photo curing. A laser beam of ultraviolet (UV) radiation focuses onto the surface of a bath of photo curable liquid resin and the laser beam draws the shape according to the sliced data onto the liquid resin. The resin solidifies wherever the light exposed, resulting in a solid layer of sliced data from CAD design. The process is repeated, layer-by-layer, until the three-dimensional object is completely built (see Figure-1).

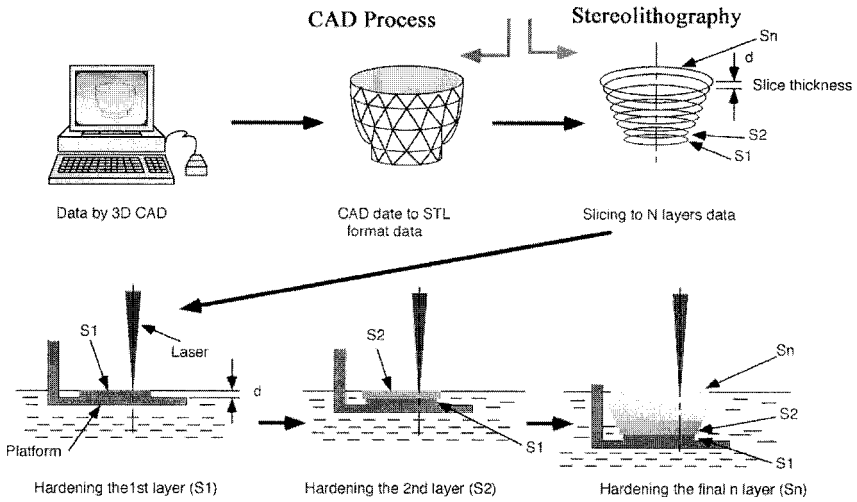

Figure 1. Process of the stereolithography

Application of the stereolithography

The product made by the stereolithography is useful for (a) verification model for a engineering design, working model for design based engineering, master model for wooden pattern, plastic die, master model for founding or master model for lost-wax, master model for vacuum casting, parts for small-quantity production and vacuum casting die, injection molding die for pre-production, and (b) a three dimensional copy for human body, shoe model, stereo map, a medical simulation model for surgery, support equipment and training model. The usage will be expanded owing to the successful development of new valuable resins. In near future, by using the stereolithography mass production parts (which can be made only by the stereolithography) will become very popular. The fundamental technology of the stereolithography consists of four items; hardware, software, photo resin and know-how to use, whereas they are based on the key technologies for the fabricating model, all of which are required to be proven a good result.

The resin for the stereolithography

Among above four ingredients, the resin is the most sensitive factor for the stereolithography, because the customer uses a shaped plastic model for its purpose. The demands for the resin are as follows:

(a) Low viscosity

(b) Stability under visible light

(c) Hardening speed (instantaneous reaction)

(d) Compatibility of 3 dimensional polymerization

(e) Accuracy after hardened

(f) Small shrinkage

(g) Various advantageous mechanical properties

(h) Safety for human body

Among them, (c) hardening speed and (d) compatibility for three dimensional (3D) polymerization are prominent factor for the resin. In order to get 3D model by the method, more than hundred or thousands layers are needed to laminate by each 0.1 mm or 0.2 mm cured layer. Thus, hardening speed of the resin is quite important to complete the model within a limited time. An exposing time at one point by a UV laser beam is the range from microsecond to millisecond, which is almost corresponding to the lifetime of exited state of the photo initiator used. This is why we have to use poly-functional oligomer or monomer to get the suitable reaction speed. This causes the poor properties of the cured material. The compatibility of the layer-layer reaction is in another point to be considered for laminating in the fabrication. We have to pay much attention to the delaminating of one layer to the next layer during fabrication.

Classification of the resin

The photo-curable resin contains photo polymerizable oligomer, monomer, reactive diluent and photo initiator, reaction promoter, additive or colorant is added if needed. The resin used for the stereolithography is classified into two categories by the reaction type of its mechanism. One is the radical reaction type, the other is cation reaction type. Urethaneacrylate (UA) based resin is typical for the radical reaction type, and epoxy based resin is for the cation reaction type, and they are well accepted. Although they have advantages and disadvantages in their properties, they are used for the purpose. Photo radical initiator is used for the UA based resin; on the other hand, hybrid system containing photo

cation initiator and photo radical initiator is used for the epoxy-based resin because of enhancing the reaction speed.

The epoxy-based resin is believed to give a model with high accuracy owing to its reaction mechanism. Therefore it has been a defacto standard for verification model. From the viewpoint of material resources, epoxy compound is limited. On the other hand, a new UA can be easily synthesized by the reaction of diisocyanates with polyols. The UA has an intermolecular cohesive energy to give characteristic properties.

We focused on our efforts to develop new materials for new resins with high performance and functional properties, such as heat-stability, impact strength, tensile strength, elongation and etc. in order to expand the stereolithography technology.

Filled resin for injection molding die

We have developed a new technology to obtain direct injection molding die by filled UA based resin in 1995. The filled resin brings a new technology for the rapid prototyping. More than 200 ABS molds can be obtained by using the die made of TSR-752 resin. The filled resin has been succeeded to enhanced TSR-754 by developing a new UA in order to expand the technology for engineering plastics, PBT or PC resin molding (see Figure-2).

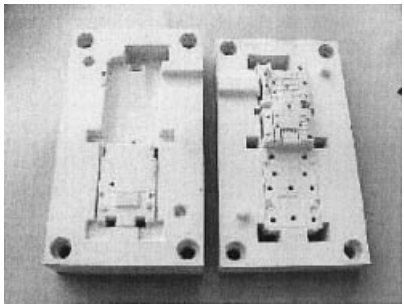

Figure 2. Injection molding die by TSR-754

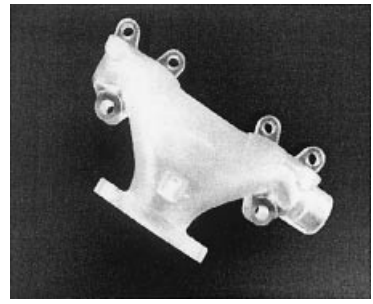

Figure 3. Model by TSR-920

The resin for functional test

The properties of the photo-cured conventional resin do not have enough properties and is not reached to the performance of ABS resin. The users are anxious to have a resin with a high performance for functional test or practical parts, even if it is not satisfied with all specification listed in. We have been investigated in the materials having clear color with high heat distortion temperature (HDT), and developed TSR-920 photo resin. The TSR-920 is consisted of a newly synthesized functional UA with acrylate monomers. A concept adopted

for the functional UA is introducing a number of segments to give high heat stability. It shows a high HDT of 120 deg-C under high load test, and having more than 7 kg/mm^2 for tensile strength (see Figure-3). It is very useful not only for the verification model but also for the mechanical parts. This resin shows unsatisfied property with some items, although we have great expectation in future advance. This will become one of the important engineering plastic cured by the stereolithography and become useful for manufacturing.

Soft and rubber like resin, TSR-1920s

It is well known that a great number of rubber or elastomer parts are produced for industrial products. The amount is estimated more than one third of plastic product for industrial usage. We designed special multi-functional UA, which shows elastic character suitable for rubber like models. The TSR 1920 is consisted of a newly synthesized UA with acrylate monomers. The TSR 1920B containing black additive is also presented for the customer who wants rubber like black appearance. Laser cured TSR-1920s are soft and flexible having clear or black color with hardness of about 70 in "Shore A" scale, useful for rubber prototype model with complex shape. The automotive and electric appliance researchers have very much attention for the soft resin to make prototypes of inner parts (see Figure-4).

Figure 4. Example by TSR-1920B

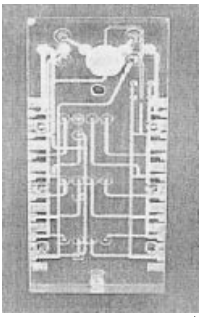

Figure 5. The part made by TSR-2090X

Super engineering plastic resin, TSR-1971

The newest filled resin, TSR-1971 is designed for the material that shows the properties of super engineering prototypes. Specially designed UA and fillers are used for the resin. The filled resin will be important when it is used for making special parts needed for super engineering plastics. Thermal expansion coefficient of linear index is very small equal level to filled super engineering plastics. Tensile and flexural modulus shows quite large and equal level to the steel. The resin is also useful special injection molding die.

Production part by the stereolithography

We have developed a new resin based on imide compounds. The new resin is useful for making production part. Recently Dr. Miyake, HITACHI Ltd., has presented a very compact water analyzer having imide based TSR-2090X part that we have developed. TSR-2090X shows a particular stability for water. By using this technique, the equipment size is reduced to 1/120 and the price is also reduced to 1/4. The new system was put into the market 1999. This is the first example that the fabricated model (Figure-5) by stereolithography is used for the production part. The fabricated product using stereolithography brings innovative technology that we have never imaged. The rapid prototyping system will become rapid production system in near future.

We are spending a lot of efforts to develop a high performance imide based photo resin in order to place position the rapid prototyping to rapid production. The resins discussed in this review are summarized in Table-1.

Table 1. Unique photo-resins for the stereolithography developed by Teijin Seiki

Resin	Characteristics	Usage
TSR-750 series	Filled with inorganic filler	Direct injection molding die
TSR-920	High HDT, clear	Functional test model
TSR-1920/B	Rubber like, soft	Rubber prototype, Medical
TSR-2090X	Water resistive, imide based	Production parts

Summary

New liquid photo resins, TSR-920, 1920/B, 1971 and 2090X, for rapid prototyping by UV Laser were developed. Hardened TSR-920 shows high HDT with high performance having clear color. This is very useful not only for verification model but also for mechanical parts. Hardened TSR-1920/B is soft and flexible having clear or black color, useful for rubber model with complex shape. TSR-1971 shows high performance very close to super engineering plastics. TSR-2090X shows a particular stability for water, and useful for production part. This is the first example that the fabricated model by the stereolithography is used for the production part.

References

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