A STUDY ON THE FABRICATION OF MULTI MATERIAL 3D PATTERNS USING INKJET PRINTING TECHNOLOGY

by
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ABSTRACT

A Study On The Fabrication Of Multi Material 3d Patterns Using Inkjet Printing Technology

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In addition to its application in media printing, inkjet printing is becoming an increasingly attractive option for the distribution and patterning of materials for a wide variety of applications such as the fabrication of prototype for the manufacturing sectors. Recently a rapid prototyping method for building parts layer-by-layer has led to interest in fabrication of prototypes with extra functionality by inkjet printing. A new system is expected which can produce assemblies composed of parts with more than one color or with more than one material. This study intends to utilize Java program to manipulate CAD design data and interface them with a modified commercial 357-nozzle piezoelectric printer with experiments focusing on the drop positioning and arrangement required to fabricate a multi material 3D patterns. Functional fluid materials such as silver nanoparticle conductive ink was successfully printed using inkjet printing technology to directly write an electronic circuit. In order to study the parameters affecting drop formation of an inkjet printer, a single nozzle piezoelectric inkjet system was also developed to study basic parameters such as voltage amplitude, firing frequency and fluid viscosity. The understanding of these parameters reactions gives a broader view on work in the fabrication of multi material 3D patters using inkjet printing technology.

九州工業大学

アブストラクト

インクジェット法を用いた複数材料立体造形に関する研究

ムスタッファ　ビン　イブラヒム

インクジェット技術の用途は単なる印刷だけにとどまらず，材料を任意の位置に配置させる技術として工業製品の試作など幅広い用途への応用が試みられている．近年，試作モデルを造形するための手法として用いられてきた積層造形技術は，インクジェット法を用いて形状確認だけでなく機能を付加した試作品の造形に関心が高まってきている．それが実現すれば複数のカラーや材料で構成された機械部品を得ることができると考えられる．この研究ではJava 言語で作成したプログラムを用いてＣＡＤで作成したデータの操作やインタフェースの作成をおこない，市販のピエゾ式インクジェットプリンタ（ノズル数 357 個）を改造したものを使用して，複数の材料を用いた立体造形に必要となる材料の配置実験を行った．また，機能性材料として，導電性材料である銀ナノ粒子をインクジェット技術で吐出し直接電気回路を描画することに成功した．その他に，インクジェット装置による微小液滴の生成に影響を与えるパラメータである振幅や噴射周波数，材料粘度に関する実験を行うために，シングルノズルのピエゾ式インクジェット装置を構成した．そして，それらのパラメータを操作し，実験を行った結果，インクジェット技術を用いた複数の材料を用いた立体造形に関するより広い見解が得られた．

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Fauzul Azim, Faruq Hanif and Fakhrul Muaz…

"Boys be ambitious!" Be ambitious not for money or selfish aggrandizement, nor for that evanescent thing which men call fame. Be ambitious for knowledge, for righteousness, and for the uplift of your people. Be ambitious for the attainment of all that a man ought to be.

This was the message of William Smith Clark, First President of Hokkaido University (Formerly known as Sapporo Agricultural College).
- By Paul Rouland 1915.

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CHAPTER 1

1.0 INTRODUCTION

The market is changing rapidly. The winners in today's competitive marketplace are those companies that can bring innovative high value products and services to the customer before their competitor does. Let us recall what a mobile-phone looked like twenty years ago ? 5 years ago ? Last 6 months ? Yesterday ? Not to mention its shape, weight and functionality as shown in Figure 1.1. Now and in the future it will be even smaller, lighter and can do much more than a prior mobile-phone such as the incorporation of camera, audio video player, internet access, location pin-pointers, scheduler and even as a cash credit device so that you can pay whatever you buy in a convenient store just by scanning your mobile-phone which is known as electronic-wallets.

DynaTAC cell phone, 1983
(Motorola, Inc.)

Sony Ericsson V800
3G phone, 2005
(Amazon.com)

Figure 1.1 : Mobile-Phone Evolution

Rapid advancements in computer technology have given life to the sudden increase of computer-aided design (CAD) related technologies, which by their speed and automation, are used to manufacture prototypes quickly and at low cost. The advancement of manufacturing technologies is being driven by the need for automation, miniaturization, cost reduction and environmentally friendly manufacturing. In recent years, the competition to send manufactured products to the market has been the prime concern for manufacturers. They cannot afford to make mistakes and once the product is released, the incorporated technology and design must work. The route of the development project must be fast, efficient and one important criteria is that all possible errors in the project are revealed as early as possible such as in the design and testing stage. It is common sense that the sooner an error is revealed the cheaper it is to correct because the further we are in the project the more costs have already been paid – such as costs if the design must be changed.

Manufacturing organizations use Rapid Prototyping which refers to the physical modeling of a design using a special class of machine technology to produce models and prototypes of injection-molded parts and metal castings products. Rapid prototyping acts as a lubricant that helps to smooth and streamline the product development process mostly to help improve time to market and as a visualization tool [1]. The Rapid prototyping industry has achieved much since its first commercial process which was presented at the AUTOFACT show in Detroit in November 1987, by a company called 3D Systems, Inc. During that time, the process was not very accurate and there are not many choices in terms of materials. Therefore, the parts obtained were considered prototypes; which is something to look at and serves as a basis for discussion. Nowadays, there are more than 30 processes some of which are already commercialized while others are still under development in research laboratories. The accuracy of the parts produced has improved significantly, and the choice of materials is relatively large whereby users can choose suitable machines and materials which suite their purposes or applications. The term "prototyping" is rather misleading since the parts or models being produced nowadays more frequently being used for functional testing or to derive tools for pre-production testing.

Yet, there are still room for growth and need for further advancement. The next task is to study this technology and make it more efficient, develop a methodology to design and optimize components made of multiple materials to enhance their functionality by using an inkjet printing technology which is one of the Rapid Prototyping technologies used to fabricate 3D objects. Multi-material rapid prototyping refers to a process of fabricating a part consisting of more than one component material from CAD models layer by layer. The benefit is to develop lighter, stronger, smarter structural components using multi-material optimization.

1.1 Overview on Fabrication of 3D objects using Rapid Prototyping Technology

Rapid prototyping is a process that is capable of converting a 3D CAD design into a physical object by means of layer-by-layer powder, solid or liquid-based manufacturing methods [2]. These technologies have also been called "layered manufacturing" or "solid freeform fabrication". In mechanical and manufacturing engineering, rapid prototyping is the process of building prototype objects to evaluate whether a proposed design is meeting the requirement in aspects such as shapes, sizes, fit and form, functionality and other requirements. They enhance the ability of designers and engineers to study the feasibility of a product and locate manufacturing problems early in the design phase. This greatly reduces costs and the time-to-market of the product. Current rapid prototyping systems are heavily used by managers, engineers, surgeons, architects, artists and individuals from many disciplines. The names of specific processes themselves are also often used as synonyms for the entire field of rapid prototyping. Among these are stereolithography (SLA for stereolithography apparatus) as shown in Figure 1.2, selective laser sintering (SLS), fused deposition modeling (FDM), laminated object manufacturing (LOM), three dimensional printing (3DP) and many others. Each of these technologies and the many other rapid prototyping processes has its own strengths and weaknesses but the basic fabrication concept are almost the same as shown in Table 1.1

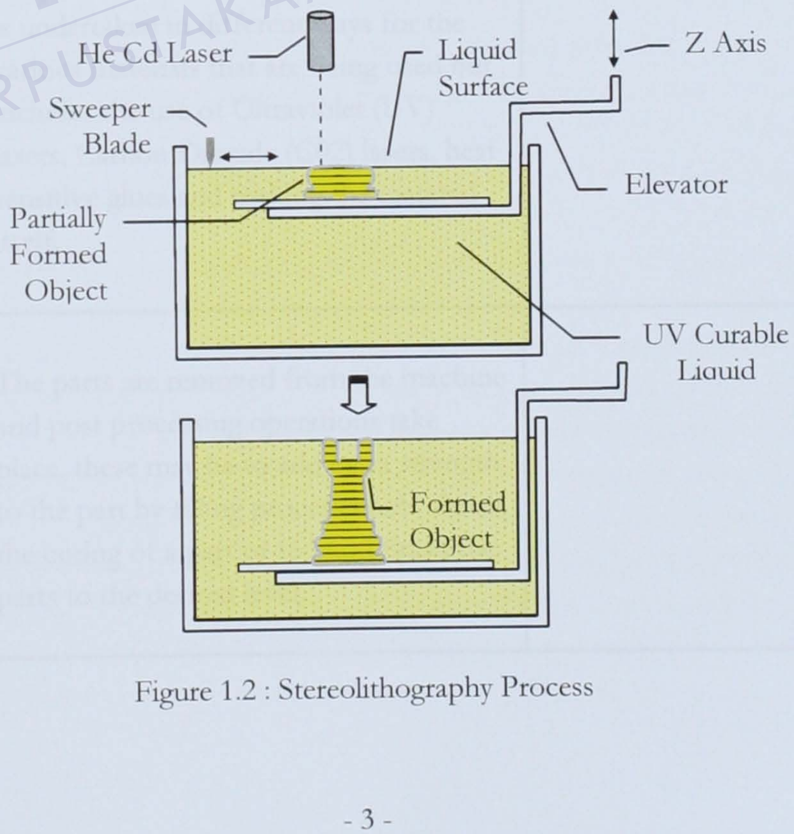


Figure 1.2 : Stereolithography Process

Table 1.1 : Step By Step Demonstration Of Rapid Prototyping Manufacture Process

Stage	Details	
1	Design is created using a 3D modeling software such as Solid Works, Pro Engineer, Unigraphics, Cadceus and etc..	
2	The 3D model is pre-processed and converted into standard triangulational language (STL- STL file connects the surface of the model in an array of triangles and consists of the X,Y and Z coordinates of the three vertices of each surface triangle)	
3	The RP process builds the parts up in layers of material from the bottom. Each layer is automatically bonded to the layer below and the process is repeated until the part is built. This process of bonding is undertaken in different ways for the various materials that are being used but includes the use of Ultraviolet (UV) lasers, Carbon Dioxide (C02) lasers, heat sensitive glues and melting the material itself.	
4	The parts are removed from the machine and post processing operations take place, these may be to add extra strength to the part by filling process voids, finish the curing of a part or to hand finish the parts to the desired level.	

1.2 Problem Statement

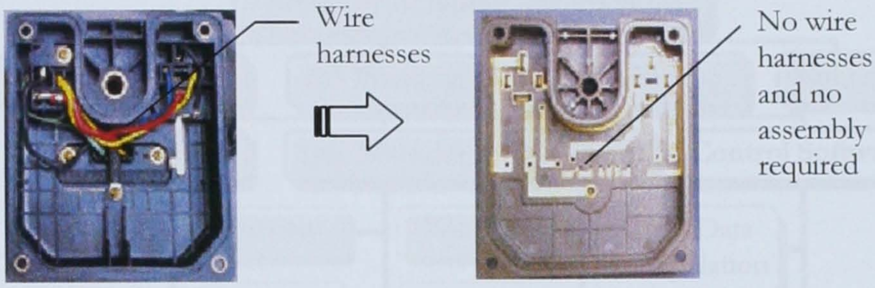
In August 3rd 2006, a Wall Street Journal article, "3D Printers Reshape World of Copying," is acknowledging the business value on the innovation of the rapid prototyping technology which can fabricate models quickly [3]. Terry Wohlers, president of Wohlers Associates, a market research firm (www.wohlersassociates.com), says that among the fastest-growing segment of the rapid-prototyping industry which had revenues of $809 million in 2005, up from an estimated $705 million in 2004 is the 3D printing technology which create physical models from computer-aided design (CAD) data by using an inkjet printing technology.

Even though inkjet printing technology has been used to fabricate 3D structures or models, parts produced by the commercially available rapid prototyping systems are made of a single material. The multi-color 3D printer from Z Corporation only prints colors on surfaces - the material beneath is still the same as the modeling material. In other rapid prototyping systems, various parts are built independently using different colors and then assembled at a later stage. A new system is expected which can produce assemblies composed of parts with more than one color or with more than one material. With this capability, some post-processing of rapid prototyping such as assembly, bonding, welding and painting can be eliminated. Figure 1.3 shows a component that was made using 3-D moulded interconnect devices (3-D MIDs). A moulded interconnect Device (MID) is defined simply as:

> "*...an injection moulded plastic substrate which incorporates a conductive circuit pattern, and integrates both mechanical and electrical functions.*"

Source: MIDIA (Molded Interconnection Device International Association)

3D MIDs are plastic mouldings that incorporate, or have on their surface, an integrated conductive pattern. As such they represent the fusion of mechanical and electrical functionally into one integrated component. MIDs often utilise three-dimensional circuitry; a circuit pattern with several planes allows better circuitry spacing, as well as the potential for integrated switches, connectors and buttons. MIDs can also reduce the number of components and cost by embedding features such as connectors, wire harnesses or lamp-holders within a single device. In addition they can be designed to be self-supporting thus eliminating any requirement for mechanical parts needed to support the circuit boards. Through reducing part numbers, MIDs save space and shorten assembly time



(http://www.primetechnologywatch.org.uk)

Figure 1.3 : A Moulded Interconnect Device (MID)

Inkjet printing have been positioned as one of the rapid prototyping systems that can produce models relatively quick and inexpensive. Among the well known rapid prototyping machines that uses the inkjet printing technology includes Z Corporation which uses inkjet to deposit a water liquid binder onto the surface of a powder material and Objet Geometries Ltd. who uses inkjet printing to deposit photopolymer and support material.

1.3 Research Overview

Recently a rapid prototyping method for building parts layer by layer has led to interest in fabrication of electrical circuits and optical devices by inkjet printing. This technology is among the rapid prototyping methods that can be extended to build multi-material assembly by adding more material inkjet nozzles to deposit materials selectively, layer by layer. The main objective of this research is to address the direct incorporation of electrical functionality into rapid prototyped parts. The idea is to inkjet print functional materials such as conductive silver nanoparticle ink on parts that was fabricated using the Rapid Prototyping technology. Whilst the main goal is to fabricate parts with functionality embedded in them, the research done in this study is still not yet complete and many obstacles still need to be addressed to. However this study has laid down some of the beneficial and important foundation work necessary for the fabrication of multi material 3D patterns using the inkjet printing technology. The overview and position of this research can be seen in the chart depicted in Figure 1.4.

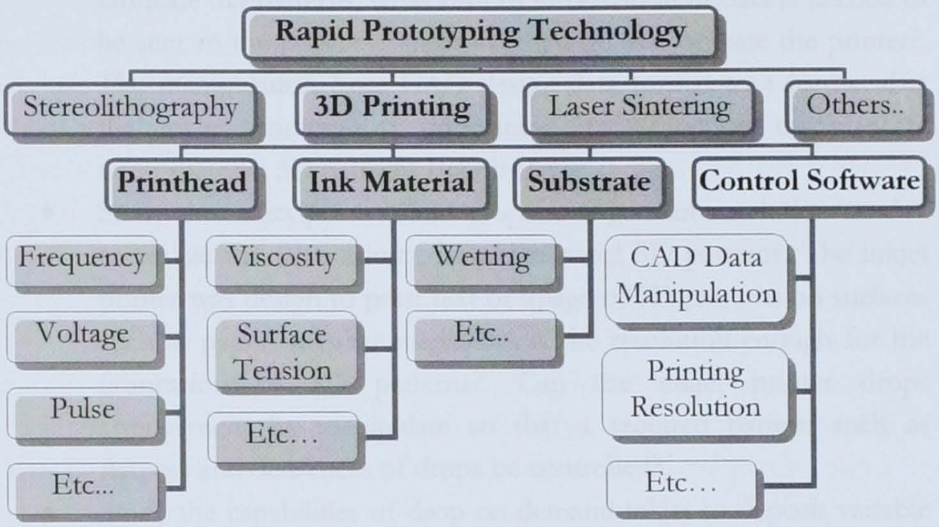


Figure 1.4 : Research Placement

The experimental work done in this study will be discussed in Chapters 4, 5 and 6 respectively. This study involves the fabrication of the inkjet printing system hardware and the control mechanism which involves the Java program software.

1.4 Aim of This Study

The specific focus of this study is to investigate the principals and exploit the inkjet printing technology to fabricate multi material 3D patterns. Since this research focuses on laying the groundwork for subsequent developments in rapid prototyped parts with electrical functionality, the specific aim for this experiments are to:

- Study the possibilities to add electrical functionality onto parts that was fabricated using the SLA technology by inkjet printing conductive silver nanoparticle ink on its surface. If the viscosity and surface tension values of the silver ink is almost similar to the printer original ink, why not just replace the original ink in the cartridge with the silver ink and inkjet print the ink to make some circuitry?.
- Study the possibilities of using inkjet printing system to fabricate multi-material 3D patterns layer by layer replicating the Rapid Prototyping process. If the inkjet printer were to be used as a tool to

fabricate 3D patterns, what kind of information or data is needed to be sent to the printer command language that operate the printer?. The manipulation from CAD design data format to a format that the inkjet printer can understand and function to fabricate multi-material 3D patterns layer by layer.

- Study the inkjet printer fluid drops arrangement resolution needed to realize the fabrication of multi-material 3D patterns. The inkjet printer was design to print text or image of 3D patterns on surfaces such as paper or other media but is the resolution enough for the fabrication of 3D patterns?. Can the inkjet printer drops arrangement be manipulate so that a required pattern such as flatness and denseness of drops be controlled?.
- Study the capabilities of drop on demand inkjet to deposit variable material by using a single nozzle drop generator. In order to deposits fluids with various characteristics, the parameters which are affecting the drop generation must be understand. With the utilization of a single nozzle piezoelectric inkjet device which function similar to the principal of the inkjet printer, the capabilities of a drop on demand inkjet printer to deposits variable fluid materials can be achieved.

1.5 Structure of This Thesis

This thesis has been organized in 7 chapters whose content are outlined as follows:
Chapter 1 which is this chapter defines the overview of fabricating 3D objects using the Rapid Prototyping Technology, statement of the problem and objectives of the research to be undertaken.

Chapter 2 provides the literature review and composed of four major sections. Multi material rapid prototyping technology overview, Rapid prototyping CAD data interface, Inkjet printing technology overview and Single nozzle piezoelectric inkjet system. Multi material rapid prototyping technology overview details work performed to date in the fabrication of multi material structures using the rapid prototyping concept. The Rapid prototyping CAD data interface presents some of the work done on manipulation of CAD data format in order to fabricate multi material 3D objects. The Inkjet printing technology overview defines the concept of the inkjet printing systems emphasizing on the drop on demand printing technology and fabricating 3D objects using the inkjet printing technology. Lastly a section on generating droplets using a single nozzle piezoelectric systems is included. This section offers an independent study on fluid materials and printing parameters for the piezoelectric inkjet device.

Chapter 3 presents the methodology used in the study which start firstly with the inkjet printing system developed to print 3D patterns. This section explains the modification of a commercially available desktop inkjet printer, the motorized stages used for the X, Y and the Z axis and the motorized stages controller utilized in the inkjet printing system. The manipulation of CAD data using Java program was included and work on the integration of the inkjet printer and Java Program was also described in the later section.

Chapter 4 shows the experimental work done on the inkjet printing of conductive silver nanoparticle ink. This sections explains the experiments done on measurement of the viscosity, surface tension, adhesion and also the electrical conductivity. The experiment on inkjet printing of the ink on SLA parts was also explain in this chapter.

Chapter 5 explains the experiment done to study the inkjet printer resolution. This involves the experiment on complement printing in-between the print-head nozzles which is 144 micron apart and also experiment on single drop deposition. This sections also shows the results on the work on the printing of 3D patterns using the inkjet printer.

Chapter 6 describes the experimental work on the fabrication of a single nozzle piezoelectric inkjet system developed to study the piezoelectric inkjet parameters affecting the drop generation of fluid. Some critical parameters such as fluid cavity length, amplitude voltage and fluid material with variable viscosity and surface tensions value were experimented so that the capability of inkjet printer to deposits functional fluid material can be understood. This chapter also explains a case study done on fabricating conductive tracks on ABS parts that was built by a FDM Rapid Prototyping machine using the single nozzle inkjet system by controlling the motorized stages.

The final chapter presents a review of the research goals and provides a summary of the results obtained from the investigation. This chapter also provides recommendations and suggestions for future research to continue this area of research. Figure 1.4 shows the structure of this thesis.

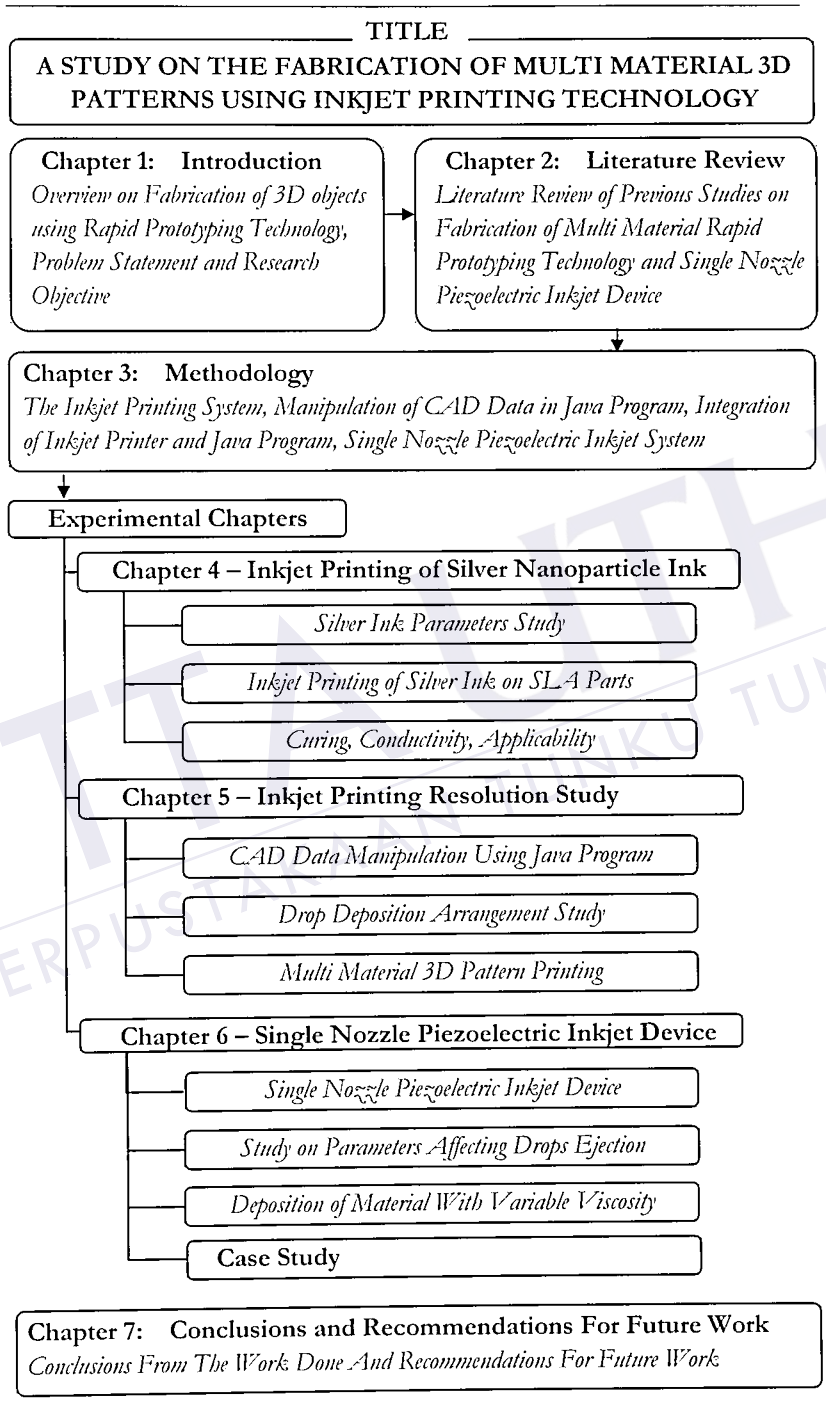


Figure 1.5 Structure of The Thesis.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Multi Material Rapid Prototyping Technology Overview

Rapid Prototyping technology have been developed rapidly in the last decades. An attractive and powerful feature of this technology yet to be fully exploited is the ability to deposit several materials between layers. Also, by depositing different materials, in varying proportions, the part can be fabricated with varying microstructure. The deposition of material in Rapid Prototyping processes can be controlled thereby providing unique opportunities to selectively deposit material. The material deposited can be varied from to region to region to create a multi-material object or, varied continuously to yield a heterogeneous object. An example of this is Laser Engineered Net Shaping (LENS^{TM}), used to fabricate near-net shaped-fully dense metal components which can control material composition throughout any given layer. This research was done at Sandia National Laboratories, USA and the parts can be fabricated from stainless steel alloys, nickel-based alloys, tool steel alloys, titanium alloys, and other specialty materials; as well as composite and functionally graded material deposition[4]. Another example is from the University of Texas, USA, who is developing the selective laser sintering process, called Multiple Material Selective Laser Sintering (M2SLS), to permit the material composition of components to be varied in a controlled manner. The parts or models of this nature that exhibit variable material properties, or heterogeneous models, cannot be easily represented in a 3D format for data exchange interfaces[5]. All of the researches mention above have been concentrating on the use of powder as the base materials to fabricate 3D objects with the use of laser as the binding or joining element. Since powder was used in these equipment, the changing of materials for the fabrication of multi-material objects will be a challenging issue. A more recent research that is still under development is from the University of Michigan, USA which is trying to fabricate multi material heterogeneous components by using hopper-nozzles designed for depositing thin layers of multiple patterned materials followed by selective laser sintering for consolidation to desired densities as shown in Figure 2.1 [6].

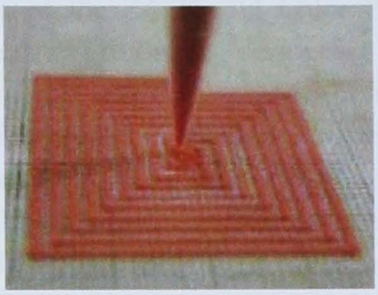


Figure 2.1 : Pattern Depositions Using Hopper Nozzles

Another research which is also still under development is from the Osaka University, Japan. They are doing research on the mixing of functional nanoparticle powder with photosensitive resins used in the micro stereolithography process as shown in Figure 2.2. They have successfully mixed nano-ceramic particles (Al_2O_3-SiO_2) with photosensitive resin with good fluidity, good particles dispersibility to manufacture ceramic reinforced parts with hardness level 3.8 times higher compared to the original resin [7]. Recently they have manage to mixed the photosensitive resin with a conductive micro particle powder to get some electrical conductivity in the fabricated parts. The experiment results shows that the parts conductivity level increased as the ratio of the powder in photosensitive resin increased [8]. This study uses the basic of stereolithography approach but the binding or resin curing using the white light is not from the top but from the bottom. Probably this is due to the fact that the mixed resin is an opaque material which does not allow light source to pass through or focus to the bottom of the resin container.

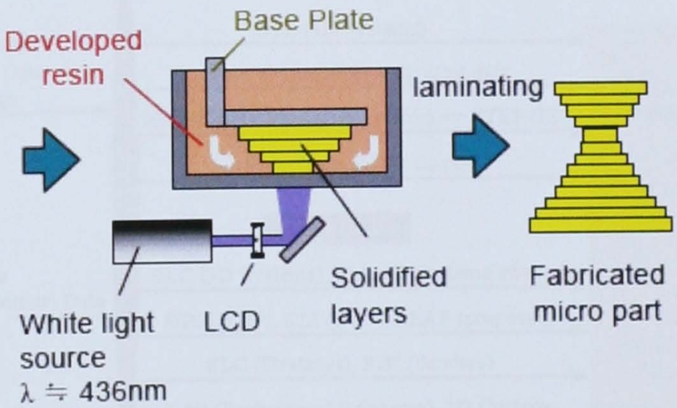


Figure 2.2 : The Micro Stereolithography Process

The addition of multiple color into a model can also be regarded as a change in the material properties of the model. On April 1, 2000 - Z Corporation

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