Agile Fabrication of a Sample by a Solid Freeform Fabrication System

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Abstract: This paper presents the basic concept of a Solid Freeform Fabrication System using a rapid prototyping procedure. The system can fabricate a ceramic model by laser cutting, accumulating, laminating and sintering of each slice. The system is mainly equipped with a laser apparatus, an x-y table, a material transfer system, and an electric oven. The system could fabricate a small object with smooth surface within comparatively short period of time. The system has also shown its effectiveness in terms of the direct application of the object without the secondary mechanical process. The fabricated sample could directly be applied and used to fairly wide practical areas.

1. Introduction

Since the first rapid prototyping system was commercialized at 1989, rapid prototyping systems have been widely used in various fields of industry[1]. Many different types of rapid prototyping process have been developed, but most of them use polymer as the basic material of the products. The application of the rapid prototyping process has been limited to the visual aids of 3D CAD design or the verification of assembly of parts because the polymer materials of rapid prototyping products have limitations in strength, durability, and heat-resistance[2-4]. In order to use more durable material such as metal or ceramic, some studies used the rapid prototyping products as the prototype of mold, and made metal products by casting process. However, these methods take many processing times and decrease the accuracy of products because the methods require many processing steps. Therefore, developing a new rapid prototyping process that can use ceramic or metal as the basic material is strongly required.

Present study developed a novel rapid prototyping process that can use ceramic or metal as well as polymer as a basic material. The process can produce more accurate metal or ceramic products than the previous method can do because the processing steps are much reduced. Moreover, the process can manufacture a part that is made of more than two different materials.

This paper presents the basic concept of the system, control algorithm, and the mechanical procedure. The experimental apparatus is also presented

2. Solid Freeform Fabrication System

2.1 Basic Theory

A schematic diagram of the basic manufacturing process that used in this study is shown in Figure 1. A 3D CAD data of the model is converted to the 2D cross-section data of the slices. A ceramic or metal tape of thickness 0.5-1.5mm is cut by a laser beam with the cross-section data of the slice. A 3D model was obtained by transferring and stacking the slices. The final product is manufactured by sintering the 3D model in a furnace.

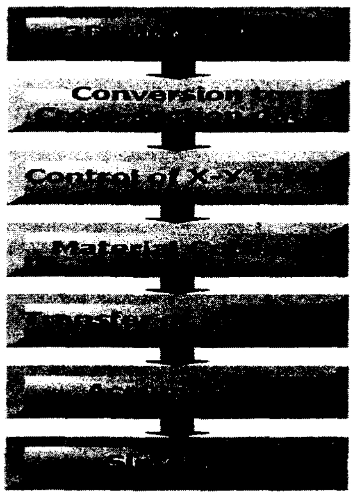

Figure 1. Schematic diagram of the present rapid prototyping process

2.2 Laser Cutting

In order to determine the specification of laser, a preliminary laser cutting test have been performed to the ceramic tapes. By considering performance and economy, a 25W CO_2 laser has been chosen. The detailed specification of the laser is shown in Table 1. A cooling fan is used to prevent the overheating of the laser system.

Two methods are possible for the laser cutting. The one fixes the material and moves the laser beam, and the other fixes the laser beam and moves the material. When the CO_2 laser beam passes through a glass, it has a characteristic that some of the energy is absorbed in the glass. Because the former uses many glass lenses, the later is chosen. Figure 2 shows the schematic diagram of the laser cutting system. A ceramic or metal raw tape is laid on a bed, and the bed is moved within horizontal 2-dimensional plane by an X-Y table. The laser is fixed in the space to set the focus of the beam is located on a point of the top of the bed. The movement of the X-Y table and the on-off of the laser beam are controlled according to the 2-dimensional cross-section data of slice. The constant moving speed is ideal for the clear cutting edge. But for the cutting of corner or edge of the 2-dimensional shape, a speed pattern of the acceleration and deceleration are given.

A gas nozzle is attached at the end of beam delivery components in order to remove particle dusts that are produced during the laser cutting process and to protect object lens of the laser system. An air compressor delivers compressed air to the beam delivery system continusously with the pressure of 0.5 atm. In order to prevent the object lens is contaminated by the lublicant of the air compressor, an air compressor of the oilless type is used. A double stage filter is installed at the exit of the air compressor to protect the object lens from the dusts and moistures in the compressed air.

Table 1. Specification of Laser

Item	Spec
Model	48-2KJ
Power ouput	25W
Test output	avg: 32.5W, min: 31W, max: 34W
Power stability	5%

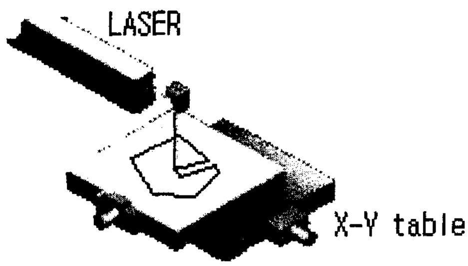

Figure 2. Laser Cutting System

2.3 Transferring and Accumulating

The raw ceramic tape should be supplied from the raw tape accumulated to the top of the x-y table bed, and the tape slice cut by the laser beam should be transferred from the bed and should be accumulated on the model accumulation bed. In order to transfer and to accumulate raw tapes and cut tape slices, a vacuum adhesion equipment and a transferring equipment were developed. Figure 3 shows a schematic diagram of the vacuum adhesion equipment. A suction pad, which is connected to a vacuum pump and a control valve, supplies vacuum to the vacuum adhesion equipment. A general purpose mask, which is composed of mesh as shown in Figure 4, is attached at the open mouth of suction pad. A thin raw tape or cut tape slice is attached on the general purpose mask when vacuum valve is opened. It is separated from the mask when the valve is closed. By controlling the vacuum pressure, it is possible to make only the cut tape slice attach on the general purpose mask while the remaining tape lie on the bed as shown in Figure 4.

Figure 5 shows a view of attaching a cut tape slide to the vacuum adhesion components. A dark area at the center is a cut material that will be used to accumulating a model, and the surrounding area is a material to be discard.

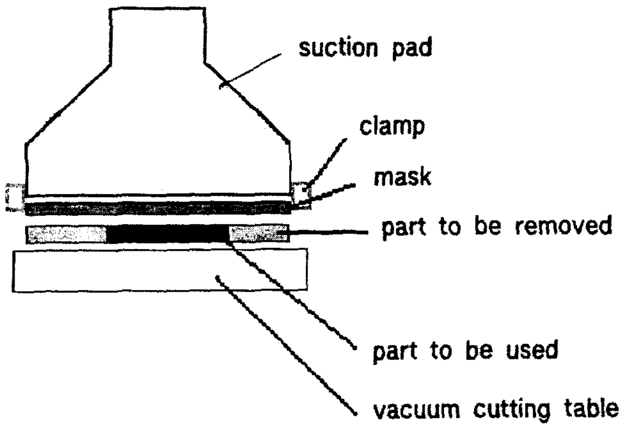

Figure 3. Vacuum Adhesion System

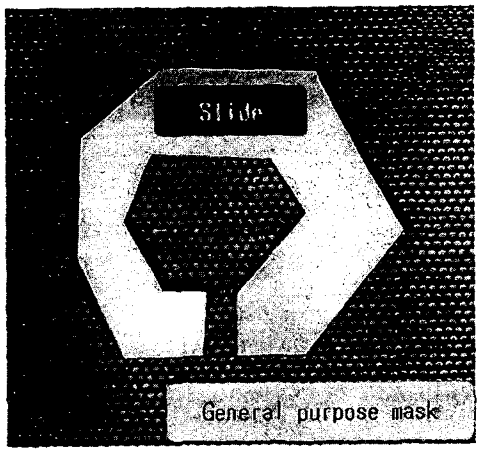

Figure 4. A slide that attached at the mask

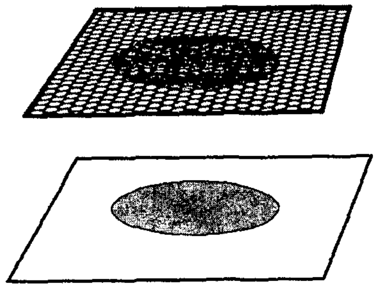

Figure 5. View of attaching a cut slide

Figure 6 is a view of the transferring equipment. The vacuum adhesion equipment is installed at the end of a horizontal bar. The other end of the bar is connected a vertical rotating axis. Two cylinders are used to rotate the vertical axis. The one rotates the axis to locate the vacuum adhesion equipment from the raw tape stack to the top of the bed of x-y table. The other rotates the axis to locate the vacuum adhesion equipment from the top of the bed to the cut material stack. The whole transferring equipment is installed at the corner of the x-y table.

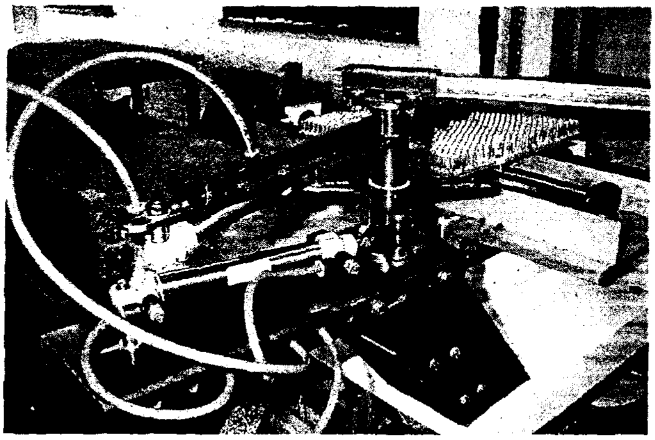

Figure 6. Transferring System

2.4 Control Unit of a System for Transferring and Accumulating

Figure 7 is a diagram of the system for transferring and accumulating. A control unit is connected at the DSP board and X-Y table. It delivers the raw material to the X-Y table and transfers the processed slide to the accumulating pad. The following is the control algorithm. An A/D converter reads the value of position detect sensor. A D/A converter sends control signal to a pneumatic drive circuit. A comparison program compares the values between the position of reference input and the position of suction pad of transfer & accumulation systems. Transfer & accumulation program governs the overall control & compensation program.

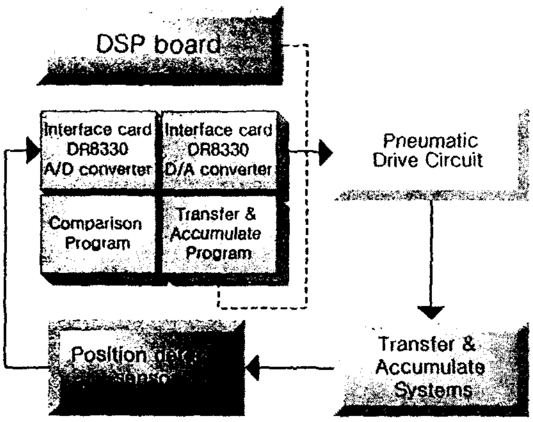

Figure 7. Control Block diagram of transferring and accumulating systems

2.5 Pneumatic Control Unit and Control Procedure

Figure 8 is the pneumatic control unit. The procedure of the unit is described as follows. Cylinder 1 and 2 are used as transfer actuators, and cylinder 3 is used for accumulation. Valve 1, 2, and 3 control the directions of cylinders. Valve 4, 5, and 6 control the speed of the cylinders. Valve 4, 5, and 6 also include decompression function to control the cylinder speed in transfer stage and prevent a sideslip of each slide.

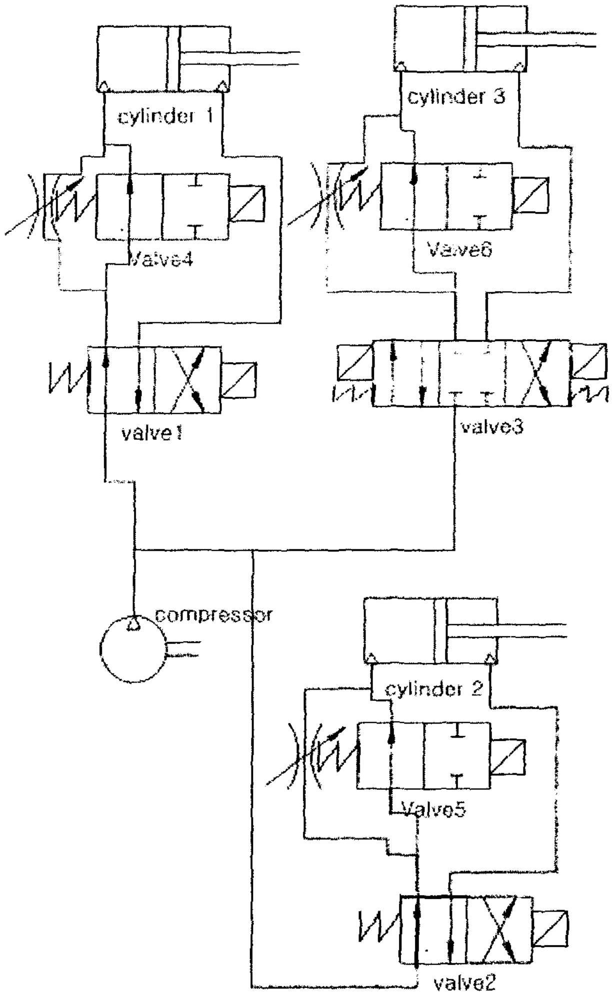

Figure 8. Pneumatic Control Unit

Figure 9 is flowchart of control process for transferring and accumulating. The first step is detecting of the home-position from DSP board signal. The second step is suctioning slide from the supply position. Then the slide is transferred to cutting position on X-Y table. The third step is comparing of cutting position of X-Y table with predetermined position for accuracy. The fourth step is sending signal from transfer & accumulate controller to DSP board. The laser cutting process is then executed. The fifth step is finishing laser cutting and detecting of home-position from DSP board. The sixth step is suctioning of slide and transferring. The seventh step is accumulating the slide onto the accumulation position. Finally, suctioning of pad returns back to the supply position.

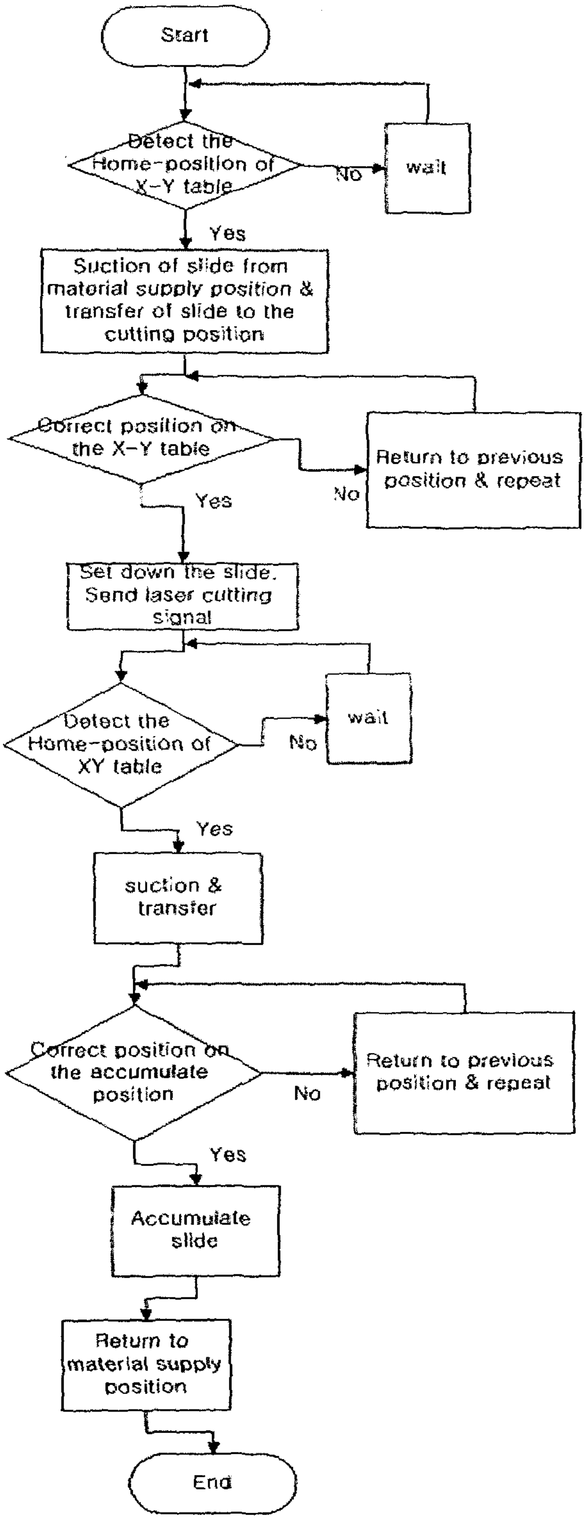

Figure 9. Flowchart of control process for system for transferring and accumulating

2.6 Experimental Apparatus

The overall view of solid freeform fabrication system is shown in Figure 10. The CO_2 laser is shown at the top of the Figure. At the end of the laser a laser beam delivery component is attached to deliver the laser beam vertically down to the object lens. The laser beam that passes through the object lens irradiate at the material slide that is located on the bed of x-y table. The bed moves two-dimensionally by the x-y table. The transferring and accumulating system is installed at one conner of the x-y table. It delivers raw slide material to the bed and transfers and accumulates the cut material to the stacking body.

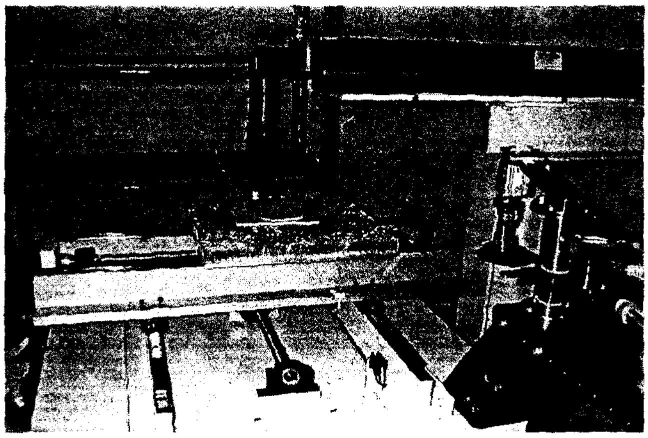

Figure 10. View of Solid Freeform Fabrication System

3. Conclusions

A novel process for agile fabrication of a sample by a solid freefrom fabrication system has been developed. Because most of the commrecialized rapid prototyping process uses polymer as the base materials, the rapid prototyping products have weakness in strength, durability, and heat resistance. The novel process can overcome these difficulties because it uses ceramic and metal as the base materials. The system could fabricate a small object with smooth surface within comparatively short period of time. The system has also shown its effectiveness in terms of the direct application of the object without the secondary mechanical process. The fabricated sample could directly be applied and used to fairly wide practical areas.

Acknowledgement

This work was supported by grant No. R01-2000-00299 from the Basic Research Program of the Korea Science & Engineering Foundation.

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