ON CERAMIC PARTS FABRICATED RAPID PROTOTYPING MACHINE BASED ON CERAMIC LASER FUSION

H. H. Tang*, H. C. Yen*, and W. H. Lin**
*Department of Mechanical Engineering, National Taipei University of Technology,
**Institute of Manufacturing Technology
Taipei 106, Taiwan

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Abstract

Conventional ceramic manufacture processes are not feasible to make ceramic parts with complex shape because of restrictions such as high tooling cost, time consuming and skillful workmanship. A new facility taking advantage of patented Ceramic Laser Fusion (CLF) technology to fabricate complex ceramic parts automatically is developed. According to the samples made by CLF machine, they are verified that hollow and over hung structures can be supported by solid green portion and complex ceramic parts can be fabricated. Apparently, this facility could promote the applications of ceramic materials, such as direct fabrication of ceramic shell mold.

Keywords: Ceramic Laser Fusion, Rapid Prototyping, Green Parts, Ceramic Shell Mold

1. Introduction

There are many restrictions on conventional ceramic manufacture processes, which are not feasible to make ceramic parts with complex shape such as turbine propeller and fan blade. Most of manufacture process are inevitable to use tooling which needs rather high cost and time for R&D. Traditionally, ceramic parts are sintered from green parts. Most of green parts are formed by powder pressing which is difficult to make complex parts.

Rapid prototyping technology makes use of layer manufacturing process. The most important advantages are there is no dead zone in working area and almost no any restrictions on shapes. No doubt, it provides a considerably satisfied method for ceramic parts manufacture. Using welding technology, complex polymer or metal parts can be fabricated by connecting some simple parts. In addition, they also can be made by NC machining. For the time being, ceramic is still difficult to be welded or machined. For the point view of shape making, the features of rapid prototyping are more sensible on ceramic than polymer and metal.

Over decades, there are some ceramic processes and systems available in different applications such as direct shell production casting (DSPC) and selective laser sintering (SLS) which had applied to mixture of polymer and ceramic powder. Recently, ceramic without binder using selective laser sintering to fabricate shell mold was developed by Wirtz [1]. To prevent from agglomeration, the layer thickness should not be thinner than 50 μm (Wirtz, 2000). Instead of powder, Tang employed ceramic slurry to develop ceramic laser fusion (CLF) process[2,3]. This process not only eliminates agglomeration, but also reduces the layer thickness. Slurry behaves as a highly viscous liquid so that the porosity can be reduced and some mechanical properties of ceramic parts can be improved (Ian Gibson, 1997)[4]. Further studying on control of shrinkage and accuracy is on the way, developing a reliable automatic machine is indispensable.

2. Intention and Method

Based on Ceramic Laser Fusion, an intention of this study is designing and setting up an automatic facility to make ceramic parts in order to raise the processing speed and extends its applications. For the purpose of reaching the ends as mentioned, we have to implement material selection, facility automation, parts making and feasibility study of direct fabrication of ceramic shell mold. All subjects will be illustrated as following.

3. The process of Ceramic Laser Fusion

The technology of Ceramic Laser Fusion (CLF) was developed by Dr. H. H. Tang, professor of Manufacture Institute of Technology, Taipei University of Technology. It can fabricate ceramic parts with very complex shape. Owing to high heat-resist, the application of the parts made by this process will be extensive.

3.1 Process Description

Fig. 1 illustrates the process details. Special made ceramic slurry (1) supplied from feeding device paves a membrane (2) on platform and is heated by drying device to produce a green part (3). Platform descends a layer thickness (4), then laser scans selectively right away (5) to directly fuses membrane from green material to ceramic. Process will repeat steps from (2) to (5) until the 3D part (6) completed. The final stages are to remove the portion (7) which is not fused by laser and takes out the ceramic part (8).

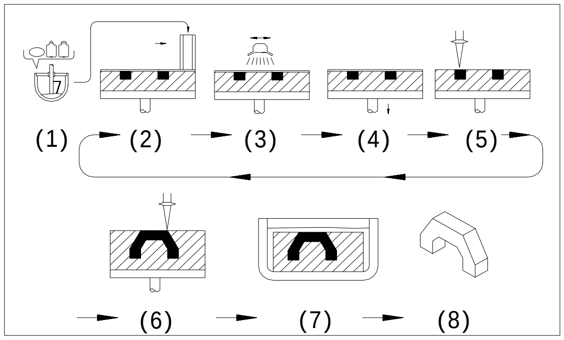

Fig. 1 CLF process

3.2 Material Selection

Raw materials used in this process are SiO_2 powder and inorganic binder. They are diluted by water uniformly.

The pores among ceramic particles can be filled by inorganic binder which is also helpful to get rid of air in pores. Even under high temperature of fusing, the movement of ceramic particles will be prevented because of little amount of expanded air and binding effect of the binder. Under the phenomenon mentioned above, this process can use high energy leaser beam to fuse the green parts, ceramic particles will not be moved upon heating. After melting and solidification, particles will not congregate [2]. For the purpose of getting well mixed slurry in order to make green parts, raw materials will be blent by a blender.

4. Design and Manufacture of an Automatic CLF Prototyping Machine

An automatic CLF rapid prototyping machine includes a mechanical system and a control system. Mechanical system is comprised of a laser scanning device and a layer making device. The function of the control system is to direct the processing sequence and monitor the whole process. We will discuss each system as following.

4.1 Mechanical system

In this study, the function of the laser scanning device is provided by an existing engraving machine, the key components, the layer making device and the control system are designed by our group. The function of laser scanning device is to make 2D cross-sectional hatching scanning. The layer making device has to execute slurry feeding, layer paving and drying, residual slurry clearing, and platform descending.

4.1.1 Laser scanning device

The existing engraving machine is shown in Fig. 2. Owing to laser absorption rate of ceramic green parts is over 90%, we select CO_2 laser as heating source. Vector scanning is implemented because of an easily creating of scanning path. Scanning speed can not be pretty high because of a relatively low laser power, 50W.

Fig. 2　Engraving machine

4.1.2　Layer making device

Layer making device is a key technique in CLF process. It is similar to Doctor Blade in Tape Casting [5], paves slurry evenly on a plate and then let it dry. Fig. 3 illustrates the CLF layer making device which includes slurry feeding unit, layer paving unit, drying unit, clearing unit for residual slurry, and platform elevating unit.

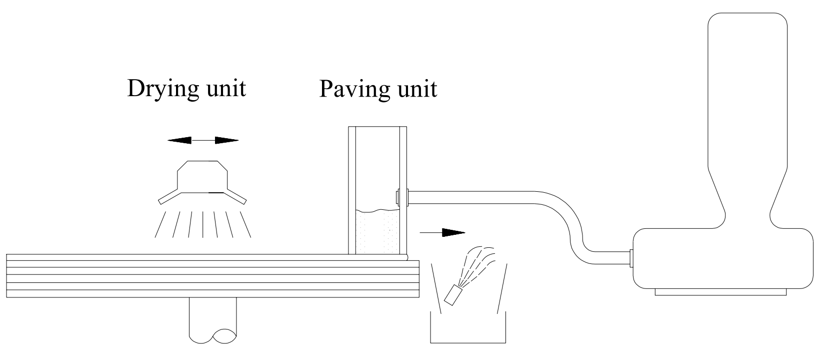

Fig. 3　CLF layer making device

4.2　Control System

The purpose of the control system is to develop highly intelligent process equipment and to achieve an automation of CLF process to reduce manufacturing time and promote the stability of process. Just after setting some basic process parameters by an operator and pushing the start button, the system will run fully automatically. Less experience and technique are required for the machine operator.

Design of control system focuses on integrating all of the individual devices and writing man-machine interface software. For the time being, an automatic CLF rapid prototyping machine has been constructed and tested as well by this group. We will discuss control hardware and control software so-called man-machine interface.

4.2.1 Control Hardware of CLF Rapid Prototyping Machine

The control system of CLF rapid prototyping machine integrates the laser scanning device and layer making device. Using process computer and programmable logic controller (PLC) conducts the sequence control. Fig. 4 is the structure of control system. Process computer and PLC together control the activity of each device in the laser making device to manufacture green layer. Process computer transfers HPGL files to laser controller and path controller that control CO_2 laser and X-Y plotter respectively.

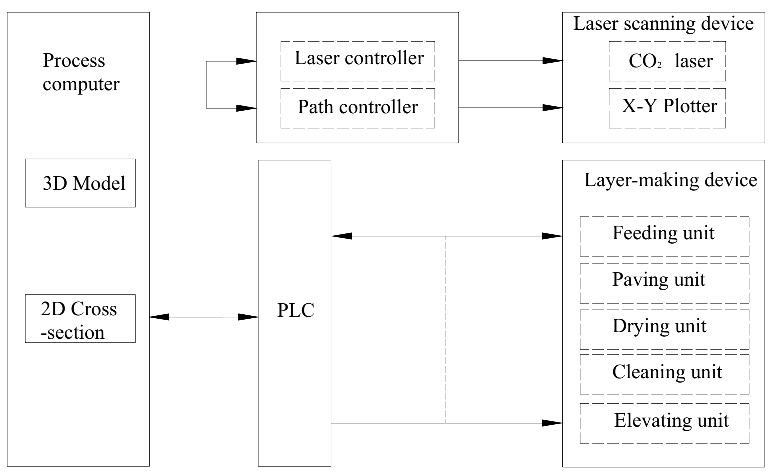

Fig. 4 Structure of control system

4.2.2 Man-Machine interface Programming

Application software for CLF machine named CLF man-machine interface is developed in Visual Basic language. This program, which comprises of two sections – monitor and control, can communicate with PLC and laser scanning device.

Monitor section traces the state of each process and indicates it in terms of color lamps.

“Red” represents system is under operation, “green” represents stop. Control section includes “Manual” and “Auto”. System’s default is “Manual”. Under “Manual” mode, individual devices can be operated manually. This mode can be used for checking the functionality of the CLF machine. If you choice “Auto” mode, system will follow the parameters set by operator and program to complete all steps.

In “Manual” mode, if one of the devices is running, other control buttons cannot be activated at all. If plotter is still, the laser scanning head has to be in origin and light sensor will be activated. The state of light sensor will indicate that plotter has left from origin or not. For the safety reason, whole system cannot be operated when plotter isn’t in origin.

In “Auto” mode, software will open a recording file to record information such as finished steps and time consuming of each layer. In case of power failure or extraordinary system stops during operation, operator can get details of finished steps from this file, and then operate manually to complete the unfinished procedures and return to “Auto” mode to continue the operation of following layers.

On the right bottom of monitor displays time consuming of last layer and total time consumption for all layers. Some useful information, such as current paving layer number and 2D file name of scanning, are shown on monitor. This information will help operator to handle the layer manufacturing process easily.

5. Parts Making

Drawing a 3D model by PRO/ENGINEER is the first step of CLF, then using slicing software which is developed by our laboratory to create hatching files, they will be transferred to control program to drive laser scanning device in order to scan the 2D hatching selectively. Using the high temperature induced by focusing the laser beam fuses ceramic green part. By means of elevating the platform, process will repeat layer by layer. Finally, it will pile up a 3D solid ceramic prototype as our designing.

After paving and scanning, work piece should be cleansed to remove un-fused material in hollow. High pressure water spouts out from faucet or nozzle to remove most of un-fused materials. However, it has to be placed into a supersonic cleaner to remove all small green portions which weren’t cleansed by water.

According to the experiments of feasibility, we can get better fusing result under the condition of laser power 50W, scanning space 0.2mm, scanning speed 20 mm/s and layer thickness 0.15 mm. In this study, all parts and direct casting shell mold are based on these parameters.

5.1 Hollow parts, fan blades and turbine propellers making

Fig. 5 shows ceramic pump blades made by CLF process. They are 30 mm diameter/ 8 mm height and 15 mm diameter/ 4 mm height respectively. One of the most important features is there are solid supports in hollow portion so that this process can make complex ceramic parts with internal cavity. Un-fused materials in hollow portion can be removed easily by putting parts into a supersonic cleaner which fills with NaOH solution.

Fig. 6 shows fan blade and turbine propeller made of ceramic. They certify that CLF can make 3D complex parts. Blade thickness is 1 mm and propeller thickness is 0.8 mm. respectively.

Fig. 5 Pump blades made of ceramic

Fig. 6 Fan blade and turbine propeller made of ceramic

5.2 A study of ceramic shell mold making feasibility

Owing to high temperature resistance and small deformation, CLF process might apply to direct casting mold making. In sand casting, model is used to make cavity, then the cavity is cast to get metal work piece. Conventionally, it has to make model in advance, sand core must be made for a production of internal features in hollow. This process is very complicated. Using CLF process, ceramic shell mold with 2 mm thickness can be made. It can be used for casting aluminum alloy and copper alloy to get metal work piece in a short period.

According to the accuracy requirement, 3D model with features of gating system, which is designed by PRO/E, is sliced by CLF software to build hatching information for each layer, the working procedures afterwards are similar to general part making method.

Fig. 7 represents a direct casting shell mold made by CLF process. Before casting, we can use ceramic slurry to bond upper and bottom molds. Fig. 8 shows a bonded CLF direct casting shell mold.

Bonded CLF direct casting shell mold have to be preheated to a temperature over 400℃ to vaporize water in ceramic shell mold and to enhance the filling of liquid metal in mold cavity. Following the regular process, a metal work piece is done. The finished pure aluminum casting work piece is shown on Fig. 9.

Fig. 7 A direct casting mold made by CLF

Fig. 8 A bonded CLF direct casting mold

Using CLF facility can make complex ceramic parts. Paving and control system can fulfill the requirements of 3D layering. Layering process can be accomplished automatically without any manpower involved.

Fig. 9 A pure aluminum casting work piece

6. Conclusion

Using CLF facility can make complex ceramic parts. The mechanical and control system can fulfill the requirements of 3D layer manufacturing. Layer manufacturing process can be accomplished automatically without any manpower involved.

It also verifies this process can provide solid supports in hollow or over hang structures. Complex ceramic part as turbine propeller can be made. Furthermore, CLF process is also feasible for making a high strength direct casting shell mold in a short period. For some small features and high accuracy requirements, except a proper after finishing for a smoother mold surface we can pave thinner layer to improve the internal surface of the mold. In this study, paving a green layer under 25μm is possible. Comparing to other powder ceramic processes which also can make direct casting molds, it is really a thinner layer. Therefore CLF process has an opportunity to make smoother and accurate work pieces. There are some basic requirements for rapid tooling process, such as smooth surface for easy part ejection and limited finishing operations[6]. No doubt, CLF meets those requirements and has great potential to compete with another ceramic processes in service of CAD to metal.

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