Optik 125 (2014) 3209–3213

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

On-line pH value measurement of solution on the removing support material process

Chil-Chyuan Kuo*, Yu-Teng Siao

Department of Mechanical Engineering and Graduate Institute of Electro-Mechanical Engineering, Ming Chi University of Technology, No. 84, Gungjuan Road, Taishan Dist., New Taipei City 24301, Taiwan

ARTICLE INFO

Article history:
Received 25 June 2013
Accepted 16 December 2013

Keyword:
Support material
Fused deposition modeling
Solution
pH value
Compensation

ABSTRACT

Removing support material from rapid prototyping (RP) part fabricated by fused deposition modeling is essential once the physical model is completed. Removing the support material from RP parts efficiently is an important concern because the product life cycle is shorter than before. In this study, a new on-line optical measurement system was developed to measure the pH value of solution during removing support material from fused deposition molded parts. The pH value of the solution can be predicted directly from the obtained maximum peak intensity according to the linear regression equation. The maximum discrepancy can be controlled within 4.37%. The time saving in removing the support material from RP parts up to 70.3% can be obtained by means of using the on-line measuring system for measuring the pH value of solution and compensating the pH value of solution immediately during the removing support material process.

1. Introduction

New market realities need faster product development due to global competition. To effectively shorten new product development time, rapid prototyping (RP) was developed [1]. RP is a manufacturing technology that fabricates three-dimensional (3D) physical models using the layer by layer building process that stacks and bonds thin layers in one direction. Prototyping is an essential part of the product development and manufacturing cycle required for accessing the form of a design before conventional steel tooling is made. In comparison with the numerically controlled manufacturing technology, RP technology can rapidly manufacture physical models with complex shapes without geometric restriction under more comfortable working environments. Fused deposition modeling (FDM) is one method among a few capable of developing rapid prototyping parts from a thermoplastic material such as polycarbonate, acrylonitrile butadiene styrene (ABS), investment casting wax and medical grade ABS [2]. FDM is one of the most promising RP techniques in terms of dimensional accuracy, machining speed and cost-effectiveness [3]. This system is viewed as a desktop prototyping facility in an office because the materials it uses are non-toxic and non-smelly. Physical models made by this system have a high stability because they are not hygroscopic. A commercial FDM machine uses a computer numeric controlled extruder-head which squeezes a fine filament of melted thermoplastic through a modeler nozzle. The controller activates the modeler nozzle to deposit heated plastic layer-by-layer to build the desired 3D physical models. In general, FDM machine possesses a second nozzle for fabricating the structures to support any overhanging section of the prototype. In recent years, some issues about FDM technology have been intensively studied by many researchers all over the world. These issues include surface modification of fused deposition modeled parts [4], enhancing the surface finish of fused deposition modeled parts [5–7], development of new materials for FDM system [8], development of a mobile FDM system [9], fabrication of scaffolds using FDM system [10], fabrication of fiber Bragg grating using FDM system [11] and improving dimensional accuracy of fused deposition modeled parts [12]. For practical application, support material of the fused deposition molded parts should be removed when the physical model is further employed. Thus, removing the support materials from fused deposition modeled parts fabricated using FDM system efficiently is a very critical process because the product life cycle is shorter than before. The major process parameters influencing the removal efficiency of support material were investigated in previous study [13], showing the pH value of the solution is a major factor affecting the efficiency of removing support material from the fused deposition modeled parts. Thus, on-line measuring the pH value of solution and compensating the pH value changed are critical to the efficiency of removing support materials during removing process. Although the pH value of solution can be determined by traditional methods including litmus paper and pH meter, the main drawbacks include time consuming, human error, unacceptable precision, solution pollution and long-term stability. This study is to develop an optical measurement system to on-line

* Corresponding author. Tel.: +886 2 29089899x4524; fax: +886 2 29063269.
E-mail address: jacksonk@mail.mcut.edu.tw (C.-C. Kuo).

0030-4026/$ – see front matter
http://dx.doi.org/10.1016/j.ijleo.2014.01.021

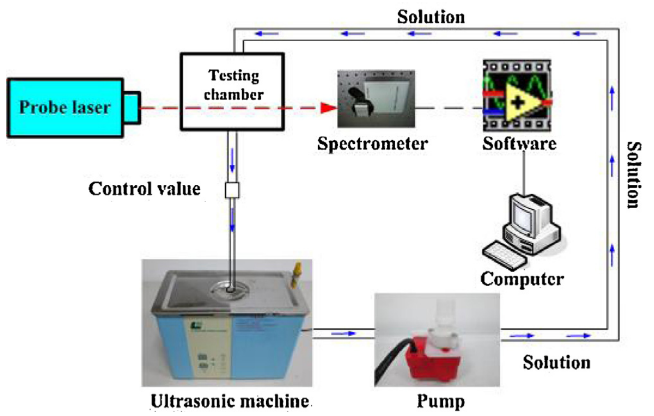

Fig. 1. Schematic illustration of the experimental setup for on-line pH value measurement of solvent during removing support material from fused deposition modeling parts.

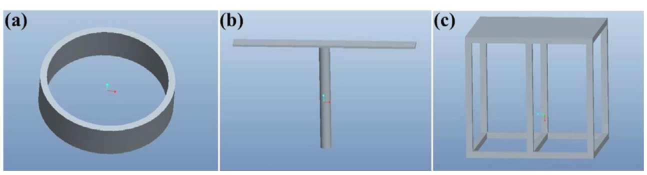

Fig. 2. Schematic illustrations of three test parts.

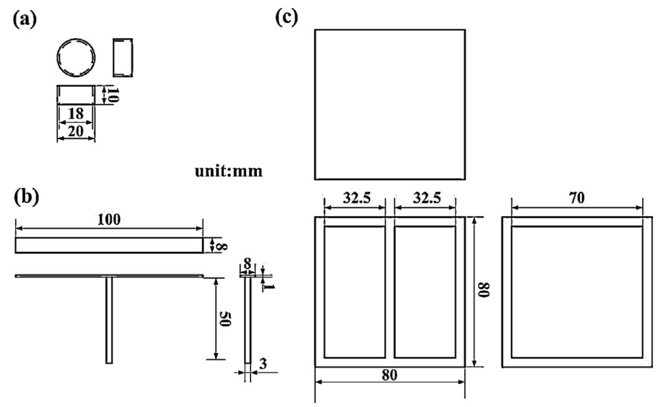

Fig. 3. Designed three test parts with given dimensions.

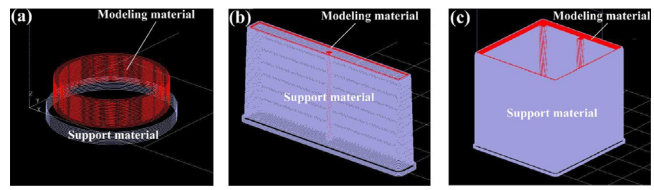

Fig. 4. Slicing results of three test parts using the CatalystEX slicing software.

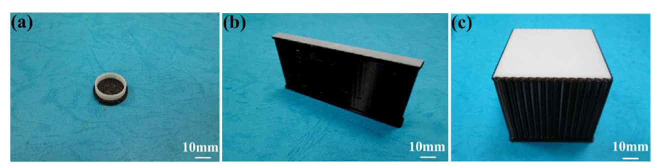

Fig. 5. Three test parts with the support structure. The white part and black part of the fused deposition molded parts indicate the modeling material and the support material, respectively.

pH value measurement of solution during the removing support material process. Linear regression equation was investigated for predicting the pH value of solution. The relative error of the linear regression equation was discussed. The time saving in removing the support material from RP parts was also investigated and discussed.

2. Experiment

Fig. 1 shows the schematic illustration of the experimental setup for on-line pH value measurement of solvent during removing support material from fused deposition modeling parts. This optical measurement system is composed of a He–Ne probe laser (λ = 632.8 nm, 0.8 mW, NT 61-337, JSD Uniphase, Inc.), a spectrometer (SV2100L, K-Mac, Inc.), an ultrasonic cleaner (1002, LEO, Inc.) and a circulation pump (M101, San Xing, Inc.) [14]. Six different pH values of solution (pH 10.5, pH 11.68, pH 11.5, pH 12 and pH 12.5) were first used to investigate the linear regression equation for predicting the pH value of solution. Then, five different pH values of solution (pH 11.13, pH 11.68, pH 12.21, pH 12.34 and pH 12.39) were used to investigate the relative error of linear regression equation. Finally, three test parts were used to investigate the efficiency of removing support material from RP parts using pH value compensation technology. Fig. 2 shows the schematic illustration of three test parts, which was designed by Pro/ENGINEER software. The model was then exported to the FDM Quickslice™ software via the stereolithography format. Fig. 3 shows the designed three test parts with given dimensions. Table 1 shows the parameters for three test parts. Fig. 4 shows the slicing results of three test parts using the CatalystEX slicing software. Once the stereolithography file has been exported to Quickslice™, it was then horizontally sliced into many thin sections for fabricating the test parts, as shown in Fig. 5. The fabricated material used in manufacturing the test parts was acrylonitrile butadiene styrene. The support materials were then removed from fused deposition molded parts by an ultrasonic cleaner when the object was fabricated. Alkaline compound (NaOH) was used to make the solution for removing support materials from RP part. Ceramic heater was used to heat the solution. The pH meter (pH 706, Tecpel, Inc.) was used to measure the pH value during the removing support material process. The pH value of solution was measured every five minutes during removing process. A digital thermometer was used to measure the temperature of solution before removing process.

Table 1
Parameters for three test parts.

No.	Layer thickness (mm)	Volume of modeling material (cm^3)	Volume of support material (cm^3)
1	0.254	0.365	0.411
2		1.362	12.273
3		40.036	113.996

3. Results and discussion

It is a well-known fact that optical measurement method has the main advantage of reliability [15,16]. Fig. 6 shows the variation in transmitted total power of probe laser before optical measurement. As can be seen, a warm-up time of at least 30 min for probe laser is required [17]. After warm-up of the probe laser, standard deviation of the transmitted total power is obviously reduced to 0.0032 mW.

To obtain the linear regression equation for predicting the pH value of solution using the on-line measuring system, six different pH values of solution (pH 10.5, pH 11, pH 11.5, pH 12, pH 12.5 and pH 13) were investigated in this study. Fig. 7 shows the peak intensity as a function of wavelength for six different pH values of solution. The counts of the maximum peak intensity for solution with the pH values of pH 10.5, pH 11, pH 11.5, pH 12, pH 12.5