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Enhancing the Efficiency of Removing Support Material from Rapid Prototype Parts using pH Value Compensation Technology

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Removing support material from rapid prototyping (RP) parts fabricated by fused deposition modeling (FDM) is required. Removing the support material rapidly and efficiently is an important concern because the product life cycle is shorter than before. The measurement of pH value in solution is an important issue affecting the efficiency of removing support material. In this work, a method was proposed to enhance the efficiency of removing support material from rapid prototype parts using pH value compensation technology. It is found that the pH value 11.6 is a good candidate for compensating the solution during removing process. The efficiency of removing support material increases with increasing the times of compensation. The savings in the removing time is up to 72 % using pH value compensation technology.

Keywords: support material, fused deposition modelling, solution, pH, compensation.

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, 2]. 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 can rapidly manufacture physical models with complex shapes without geometric restriction under more comfortable working environments. Fused deposition modelling (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. FDM is one of the most promising RP techniques in terms of dimensional accuracy, speed and cost-effectiveness. 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 nozzle. The controller activates the 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 improving the surface finish of fused deposition modeled parts [3], improving dimensional accuracy of fused deposition modeled parts [4], development of new materials for FDM system [5], development of a mobile FDM system [6], fabrication of scaffolds using FDM system [7] and fabrication of medical implants using FDM system [8]. In practice, support material of the RP part should be removed when the physical model is further employed. Thus, removing the support material from the RP part produced from the FDM-based machine efficiently is an important concern because the product life cycle is shorter than before. The major process parameters influencing the removal efficiency of support material were investigated in previous works [9, 10], showing the pH value of the solution is a major factor affecting the efficiency of removing support material from rapid prototype parts. The efficiency of removing support material is significantly reduced when the pH value of the solution is lower than 11. Thus, monitoring the pH value of solution and compensate the pH value changed are critical to the efficiency of removing support material during removing process. In this work, a new method was proposed to enhance the efficiency of removing support material from rapid prototype parts using pH value compensation. Effects of compensation point of pH value of solution and times of compensation on the removal efficiency of support materials were investigated experimentally. Some good results have been obtained and discussed. The saving in the removing time using pH value compensation was also investigated and discussed. Plastic materials are widely used in 3C products, optical elements, and electronic goods, automotive and packaging. It is well known that plastic injection molding is one of the most important polymer manufacturing processes in plastic industry because it can produce complex-geometry plastic parts with good dimensional accuracy under very short cycle time. In this study, a simple and cost-effective approach for fabricating a precision epoxy resin mold using rapid tooling technology was proposed. The Taguchi design method is an efficient and effective experimental approach that can reduce the experimental trials to determine the optimum

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level of process parameters. The correlation of the dimensional accuracy with processing parameters of plastic injection moulding is a complicated issue. Thus, the objective of this study is to determine the optimum level of process parameters for improving the dimensional accuracy of Fresnel lens during plastic injection molding using Taguchi design method. The most significant factor that affects the microgroove depth of Fresnel lens was also investigated. Twenty test parts were employed to prove the effectiveness of Taguchi design method after the optimum level of process parameters were determined.

2. EXPERIMENT

Fig. 1 shows the schematic illustration of four master pattern models, which was designed by Pro/ENGINEER software. Fig. 2 shows the four master pattern models with given dimensions. The model was then exported to the FDM QuicksliceTM software via the stereolithography format. Fig. 3 shows the slicing results of four master pattern models using the CatalystEX slicing software. Table 1 shows the parameters for four master pattern models. Once the stereolithography file has been exported to QuicksliceTM, it was then horizontally sliced into many thin sections for fabricating the master pattern model, as shown in Fig. 4.

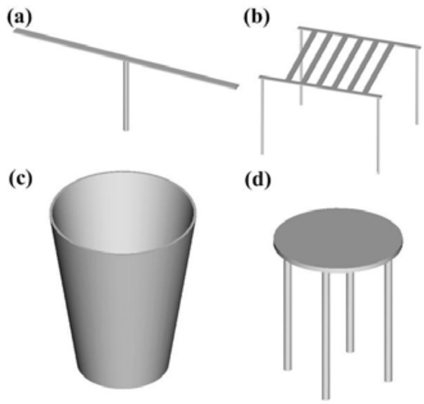

Fig. 1. Schematic illustration of four master pattern models

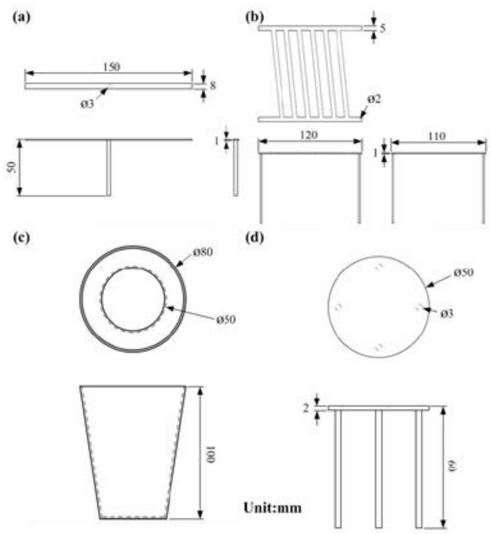

Fig. 2. Designed four master pattern models with given dimensions

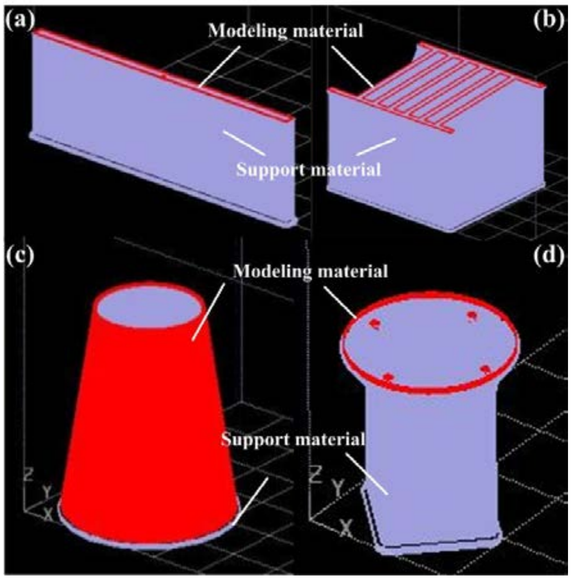

Fig. 3. Slicing results of four master pattern models using the CatalystEX slicing software

Table 1. Parameters for four master pattern models

No.	Layer thickness (mm)	Volume of modeling material (cm^3)	Volume of support material (cm^3)
a	0.254	1.37	60.01
b		6.15	132.52
c		32.26	80.86
d		5.63	50.19

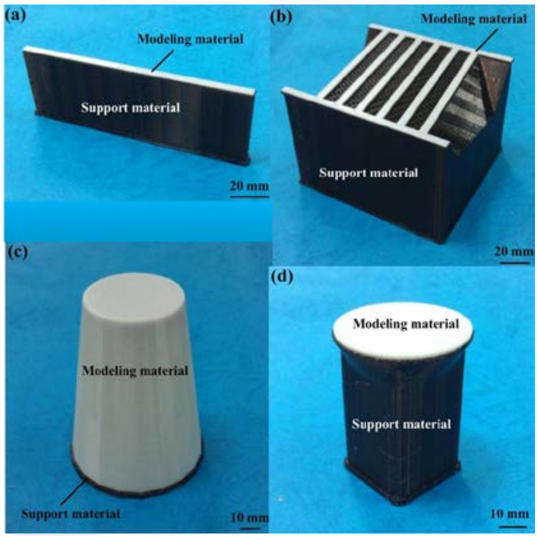

Fig. 4. Four master pattern models with the support structure. White part and black part shown in the figure indicate the modeling material and the support material, respectively

The fabricated material used in manufacturing the test parts was acrylonitrile butadiene styrene. Support materials were removed from RP part by ultrasonic machine (frequency = 46 kHz) when the object was fabricated. Alkaline compound (NaOH) was used to make the solution for removing support material from RP part. Ceramic heater was used to heat the solution. The pH value meter (pH value5011) was used to measure the variations of pH value during removing process. The pH value of solution was measured every one minute during removing process.

A digital thermometer was used to measure the temperature of solution before removing process. In general, the pH value of the solvent change with temperature. The pH value was changed to 12 when the solution was heated from room temperature to 70 °C [11]. Thus, the pH 12 of solution was set as a starting point and the temperature of solution was fixed at 70 °C during removing process. Effects of compensation point of pH value and times of compensation on the removal efficiency of support material were analyzed and discussed. Ten compensation points of pH value were employed to investigate the optimal compensation point. Three test parts were further employed to investigate the efficiency of removing support material from RP parts using pH value compensation technology.

3. RESULTS AND DISCUSSION

Fig. 5 shows the pH value as a function of the removing time without applying compensation technology. As can be seen, the entire removing time is 100 minutes. To shorten the removing time, pH value compensation technology was used. The weights of the solvent for ten compensation points are 11.88 g, 10.8 g, 9.72 g, 8.64 g, 7.56 g, 6.48 g, 5.4 g, 4.32 g, 3.24 g, and 2.16 g, respectively. The entire removing time is obviously reduced as compared with those without applying pH value compensation technology.

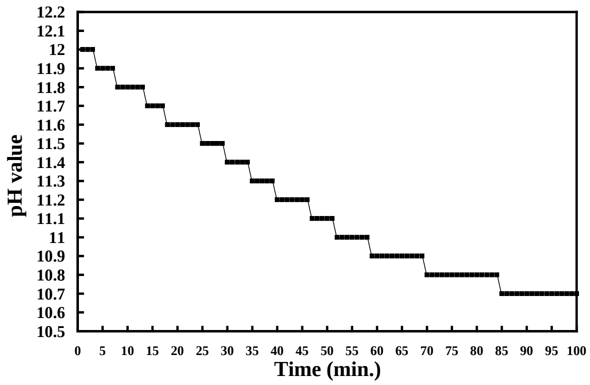

Fig. 5. The pH value as a function of the removing time without applying compensation technology

Fig. 6 shows the removing time as a function of ten compensation points. As it can be recognized from this figure, the pH value 11.6 is a good candidate for compensating the solution during removing process because the compensation points form pH value 11.6 to pH value 11.5 is too early and the compensation points form pH value 11.7 to pH value 11.8 is too late. For the compensation point of pH value 11.6, the entire removing time is reduced to only 38 minutes.

Fig. 7 shows the removing time as a function of the number of compensation time. Two phenomena were observed. One is the entire removing time decreases with increasing the times of compensation and the other is the entire removing time was significantly reduced. The entire removing time was significantly reduced to only 39 minutes by five times compensation, while the entire removing time was 137 minutes without applying pH value compensation technology. This means that the efficiency of removing support material increases with increasing the times of compensation. Fig. 8 shows the situation of removing process. To further evaluate the efficiency of removing process using the pH value compensation technology proposed, three test specimens was employed for investigation. Fig. 9 shows the removing time of three evaluation samples with and without applying pH value compensation technology.

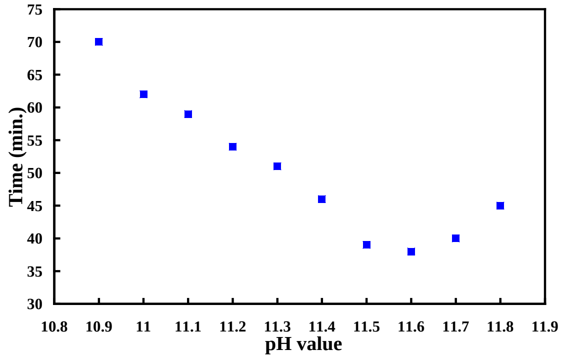

Fig. 6. Removing time as a function of ten compensation points

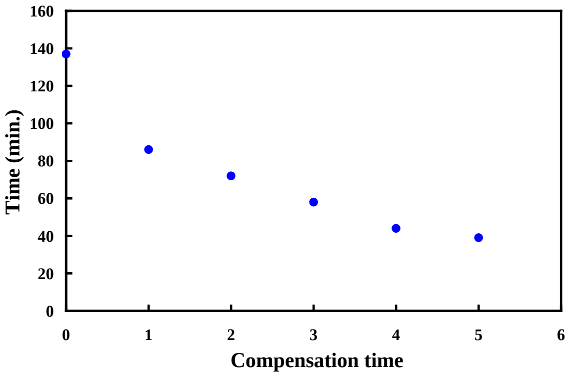

Fig. 7. Removing time as a function of the number of compensation time

Fig. 8. Situation of removing process

As can be seen, the savings in the removing time for master pattern model a, b and c is 72 %, 63 % and 63 %, respectively. This means that the savings in the removing time is up to 72 % using pH value compensation technology. Based on the results described above, compensation point and times of compensation are the two critical parameters in the removing process. But, the most important parameter affecting the efficiency of removing process is compensation point. Fig. 10 shows four RP parts after removing support materials. This technology has broad application prospects in the development of a new product using a FDM rapid prototyping system [12, 13] and rapid tooling technology [14]. Current results were performed manually. Further investigations focusing on the automation of pH monitoring with automatic compensation using microcontroller are in progress [15].

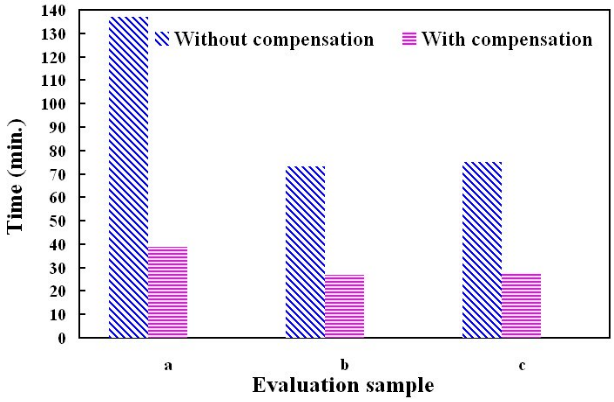

Fig. 9. Removing time of three evaluation samples with and without applying pH value compensation technology

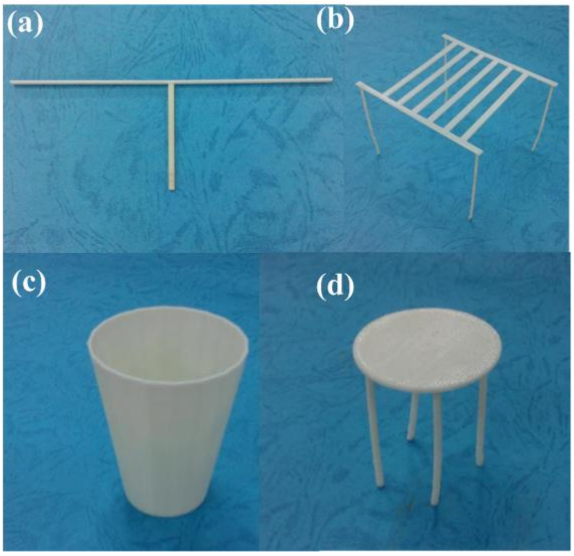

Fig. 10. Four RP parts after removing support materials

4. CONCLUSIONS

The target of RP is to reduce product development cost and lead times. A method for enhancing the efficiency of removing support material from RP parts using pH value compensation technology has been proposed in this work. The advantages of pH value compensation technology have been presented through test samples. The pH value 11.6 has been proved as a good candidate for compensating the solution during removing process. The efficiency of removing support material increases with increasing the times of compensation. The savings in the removing time up to 72 % can be reached using pH value compensation technology.

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