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A Rapid and Cost-Effective Approach to Manufacturing Modeling Platform for Fused Deposition Modeling

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Abstract**—**This study presents a cost-effective approach for rapid fabricating modeling platforms utilized in fused deposition modeling system. A small-batch production of modeling platforms about 20 pieces can be obtained economically through silicone rubber mold using vacuum casting without applying the plastic injection molding. The air venting systems is crucial for fabricating modeling platform using vacuum casting. Modeling platforms fabricated can be used for building rapid prototyping model after sandblasting. This study offers industrial value because it has both time-effectiveness and cost-effectiveness.

Keywords**—**Vacuum casting, fused deposition modeling, modeling platform, sandblasting, surface roughness.

I. 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]-[4]. 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 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. FDM is one of the most promising RP techniques in terms of dimensional accuracy, speed and cost-effectiveness [5]. 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 RP system 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 RP system 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 [6], improving dimensional accuracy of fused deposition modeled parts [7], development of new materials for FDM RP system[8], development of a mobile FDM system[9], fabrication of scaffolds using FDM RP system [10] and fabrication of medical implants using FDM RP system [11]. However, there have been few studies about the fabrication of modeling platform used for FDM RP system.

It is well-known that plastic injection molding is one of the most important polymer processing operations in plastic industry because it can produce complex-geometry plastic parts with good dimensional accuracy under very short cycle time. However, the time and cost required for producing a mold are the most troublesome problems that limit the application in the development stage of a new product in the industry. In this study, a cost-effective method for fabricating the modeling platform utilized in FDM system with was proposed using vacuum casting [12], [13]. Performance evaluations of the modeling platform fabricated were investigated using FDM RP. Surface roughnesses of the fabricated modeling platform were investigated by white-light interferometry (WLI).

II. Experiment

Fig. 1 shows the modeling platform used for FDM. Fig. 2 shows the procedures for fabricating silicone rubber mold of the modeling platform. Details about the process flow of making silicone rubber mold were based on those introduced in references [14]-[16]. The amount of silicone rubber required was calculated by multiplying the desired volume of the silicone mold to be made by the density of silicone rubber (1.07 g/cm^3 at 23°C. Depending on the extent of air bubbles in the mixture, the degassing process can range from 25 to 60 min. An automatic debubbling system developed was used for generating a vacuum environment to remove the air bubbles derived from the mixing process of the curing agent and the silicone rubber [17], [18]. Generally, the curing agent and silicone rubber in weight ratio of 10:1 was mixed thoroughly with a stirrer. The properties of the silicone rubber mold such as durability and mold life are significantly affected by the relative amounts of curing agent and silicone rubber. Thus, calculating the weight of base and curing agent precisely is crucial prior to mixing. To reduce human error, a user-friendly man-machine interface was developed using Visual Basic program. Vacuum

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casting is an indirect soft tooling process, which is a copying technique characterized by the used of a vacuum. Vacuum casting is a promising approach of rapid tooling for consumer products. A vacuum casting machine (F-600, Feiling) was used to cast modeling platform. Fig. 3 shows the situation of vacuum casting for fabricating the modeling platform. ABS resin was used as the material for fabricating modeling platform. Post cure (1h at 70°C) for the modeling platform fabricated was performed in a convection oven (Deng Yag DH400) to ensure the completion of curing reaction of the ABS resins. To verify the quality of modeling platform fabricated, uPrint RP system was used to test. To characterize the surface roughnesses of the original platform and modeling platform fabricated, the surface roughnesses were measured using a WLI (7502, Chroma). The sampling area was chosen to be 250 μm×250 μm. The arithmetic average roughness value (Ra) was used to examine the change in surface roughness during the manufacturing process, which is the average displacement of the peaks and valleys measured with respect to a mean line.

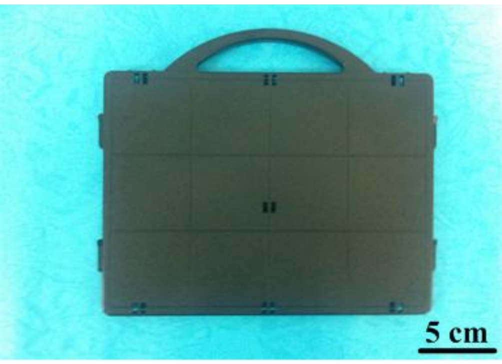

Fig. 1 Modeling platform used for FDM

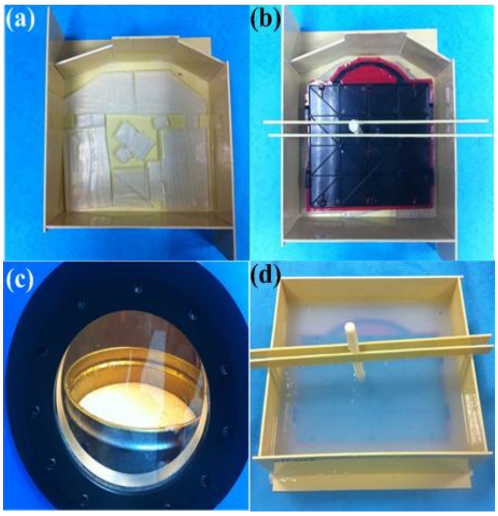

Fig. 2 Procedures for fabricating silicone rubber mold of the modeling platform. (a) placing recycled silicone rubber, (b) preparation of mold frame, (c) degassing of the silicone rubber and (d)pouring silicone rubber into the mold frame

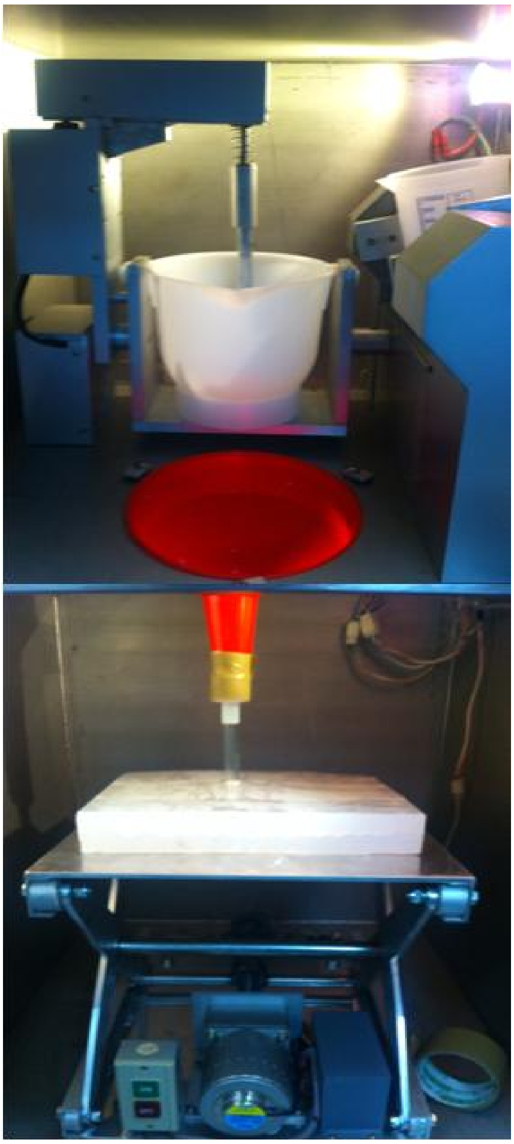

Fig. 3 Vacuum casting for fabricating the modeling platform

III. Results and Discussion

Fig. 4 shows the silicone rubber mold of the modeling platform. Air venting system and gating system were processed before vacuum casing using silicone rubber mold fabricated. To evaluate the validity of silicone rubber mold, molten wax was poured into the silicone rubber mold. The silicone rubber mold owns high chemical resistance because of the low interfacial energy of its surface [19]. Thus, a wide range of materials such as wax, ABS, plastic and metal with low melting point can be cast without any worry of possible reaction with the surface of the silicone rubber mold. Fig. 5 shows the wax pattern of the modeling platform was successfully cast from silicone rubber mold. Fig. 6 shows the silicone rubber mold of the modeling platform with ABS materials using vacuum casting. Fig. 7 shows the fabricated modeling platform. As can be seen, the structures of the modeling platform were completely duplicated using vacuum casting. The modeling platform fabricated can be easily separated from the silicone rubber mold because silicone rubber mold has high flexibility and elasticity. The properties of the modeling platform were significantly affected by the air venting system. Thus, the air venting systems is crucial for fabricating modeling platform. Besides, no any defects such as flash, air trap and short shot were observed in the modeling platform [20]-[23]. Fig. 8 shows the size verification of the modeling platform fabricated using the uPrint RP system. No any dimensional interference was found while inserting the modeling platform fabricated into the modeling stage of the FDM RP system. This result shows that the modeling platform fabricated has no obvious warpage. Fig. 9 shows the building RP parts verification of the modeling platform fabricated using the uPrint RP system. As can be seen, RP parts cannot be built on the modeling platform fabricated. This is because the surface roughness of the modeling platform is lower than that of the original modeling platform. Fig. 10 shows the surface roughnesses of the original modeling platform. Fig. 11 shows the surface roughnesses of the modeling platform fabricated. To increase the surface roughnesses of the modeling platform fabricated, the sandblasting was carried out [24]. Fig. 12 shows the surface roughnesses measured by WLI of the modeling platform after the sandblasting. The surface roughness of the modeling platform was increased from 3.27 μm to 4.31μm, which is close to that of the original modeling platform. After the sandblasting processing, five RP parts can be built in the modeling platform fabricated successfully, as shown in Fig. 13. This result shows that the modeling platforms fabricated using vacuum casting can be employed to build physical model using FDM RP machine. Plastic injection molding is a common approach for fabricating the modeling platform used for FDM RP system. However, the plastic injection molding processing conditions are complex, causing low successful rate in the manufacturing of modeling platform. The estimated cost for manufacturing a silicone rubber mold was only NT$ 1,764. In general, the silicone rubber mold fabricated can be used for low volume production by vacuum casting. About 30 modeling platforms can be fabricated from this silicone rubber mold due to lifetime of silicone rubber. The estimated time of manufacturing the modeling platforms was only two hours. Based on the above study, the results show that the modeling platforms can be produced rapidly and cost-effectively without applying plastic injection molding [25]. In addition, the elasticity and flexibility of silicone rubber mold gives silicone rubber tooling a competitive edge over hard tooling.

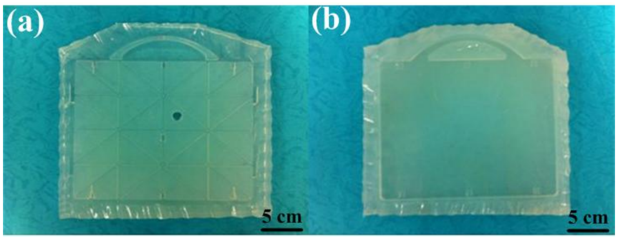

Fig. 4 Silicone rubber mold of the modeling platform (a) core insert and (b) cavity insert

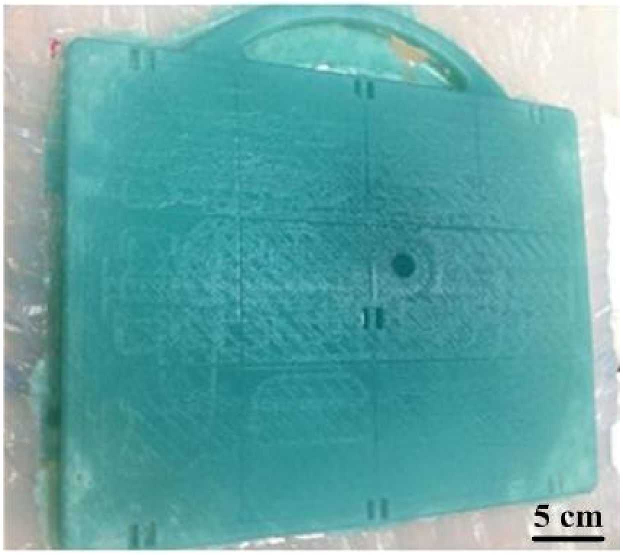

Fig. 5 Wax pattern of the modeling platform cast from silicone rubber mold

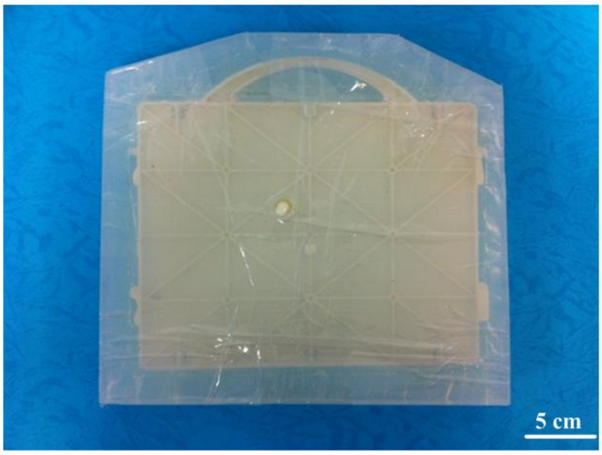

Fig. 6 Silicone rubber mold of the modeling platform with ABS materials using vacuum casting

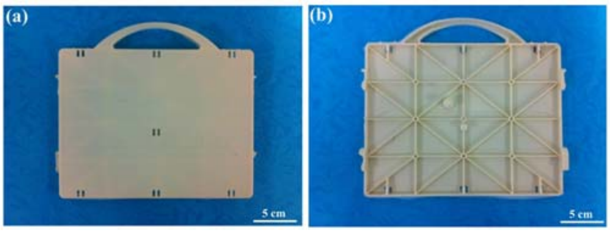

Fig. 7 Fabricated modeling platform (a) frontside and (b) backside

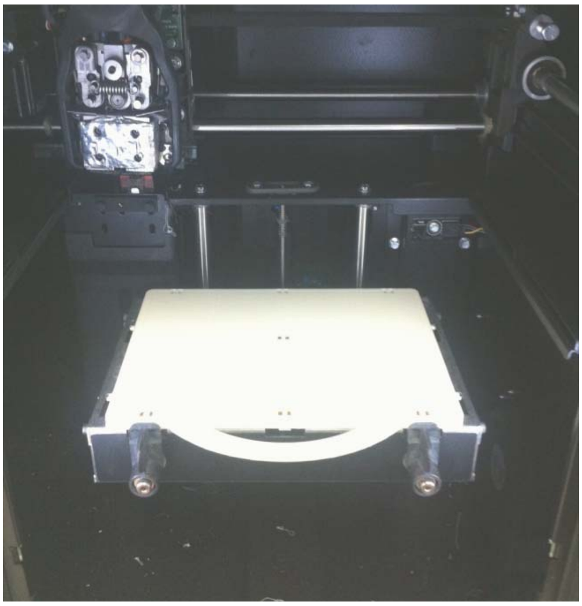
Fig. 8 Size verification of the modeling platform fabricated using the uPrint RP system

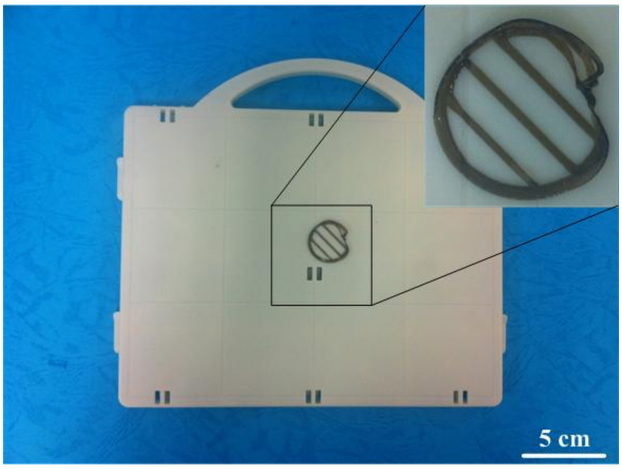

Fig. 9 Building RP parts verification of the modeling platform fabricated using the uPrint RP system

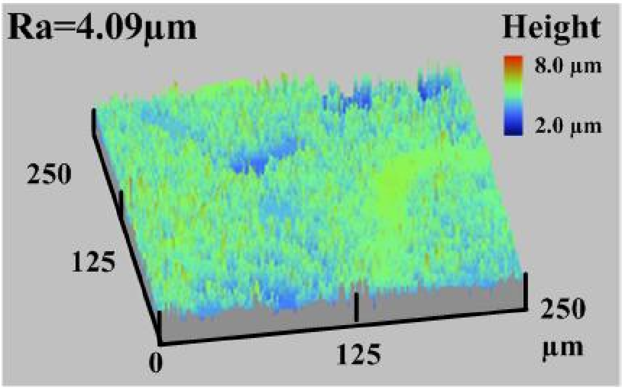

Fig. 10 Surface roughness of original modeling platform

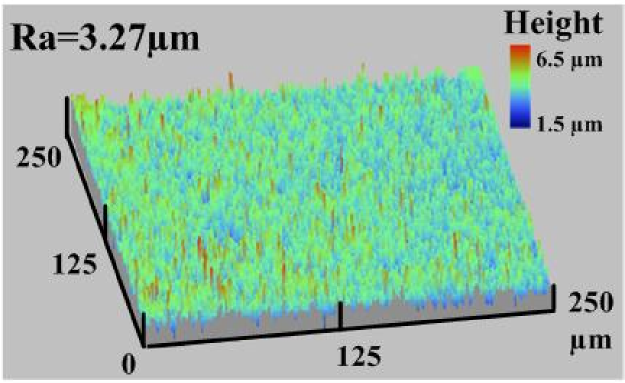

Fig. 11 Surface roughness of the modeling platform fabricated

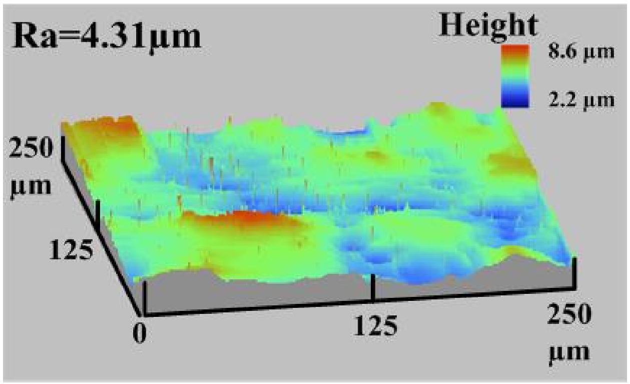

Fig. 12 Surface roughness of the modeling platform after sandblasting

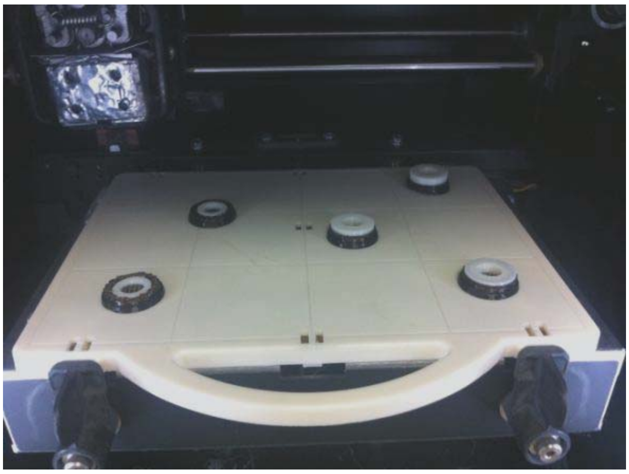
Fig. 13 Five RP parts were built in the modeling platform fabricated after sandblasting

IV. Conclusions

The research results of this study have industrial application values because this study demonstrates a cost-effective method for small-batch production of the modeling platforms efficiently without the use of plastic injection molding. It was found that the air venting systems is a key technology for fabricating modeling platform via silicone rubber mold using vacuum casting. Performance test verified that the sandblasting is the key process affecting the performance of the modeling platforms fabricated.

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