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Surface Color Optimization of Powder-based 3D Objects Based on Impregnation Process

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Abstract

Poor surface color reproduction and incomplete color management system are the main impeding factors for the commercialization of full-color 3D printing. In this paper, the coloration mechanisms as well as characteristics of 3D surfaces were introduced, and a variety of impregnation methods suitable for powder-based 3D printing were integrated. The 24-color cards and four-primary cubes were printed by 3D Systems ProJet 860 Pro printer to compare single-plane and multi-plane optimization effects, choose the best impregnation process and put forward a guide to improve impregnants. The results revealed that the saturation of 3D printing surface color was greatly increased and the brightness was slightly decreased after impregnation process, which reduced chromatic aberration on single-plane or multi-plane. ColorBond and transparent coating spray are the most suitable combination for powder-based 3D objects. Increasing the uniformity, transparency and permeability of coatings is beneficial to further optimize surface colors.

Keywords *: Full-color 3D printing; Powder-based 3D printing; Impregnation Process; Color reproduction; Color optimization*

1. Introduction

Powder-based 3D printing was firstly developed and patented by Massachusetts Institute of Technology based on the technology of three-dimensional printing and gluing (3DP) [1, 2]. With further developments in printing process and color binder, it has become the most widely used full-color 3D printing technology for industries concerned with customized 3D models, packaging, and creative product development [3].

However, the change in surface color since the redundant gypsum or ceramic powder adhere to color binder as well as the color inconsistency between upper face and side faces of a products will reduce the accuracy of color reproduction. Impregnating process is the most effective to improve the accuracy of color reproduction at present and has been counted as an important step in printing process by powder-based 3D printer manufacturers [4].

In the present research, the effects of post-processing on surface color reproduction of five different types of impregnated powder-based 3D-printed objects were explored. And two impregnating methods were picked on the basis of the assessment method to compare the differences in color optimization effect across multiple faces.

2. Experiment

2.1 Samples for printing and processing

Basic materials needed in the printing process, visijet PXL powder and color binders, were provided by 3D Systems. Further, a 24-color card was developed in Adobe Photoshop software using ColorChecker Classic (X-Rite), which provides a good range of colors and grey tones in color imaging field [5], and subsequently, the test card was mapped into the upper surface of a substrate (120 mm × 80 mm × 8 mm) in 3DMax software. Moreover, prior to the printing of the test plates, all of the nozzles and bearings of the Project860 Pro 3D printer (3D Systems) were thoroughly cleaned as well as color binders and cleaning fluid were replaced with new ones. Five test plates were first printed and dried in a constant temperature (22°C) and humidity (35%) for five hours and then divided into five groups in order to measure different impregnation parameters. The CT group was the original test plate (without any post-processing), and the processing methods of the remaining four groups are presented in Table 1. The impregnating time for ColorBond and the cyanoacrylate infiltrant were set to 20 s and 3 s, respectively.

Tab.1 Five impregnation methods

Group	Material	Brand	Processing method
CT	None	N/A	N/A
CB	ColorBond	3D Systems	Soakage
CC	ColorBond + Clear Coat	3D Systems; Krylon	Soakage + Spraying
DE	Double component epoxy resin adhesive	Ergo	Coating
CY	Cyanoacrylate infiltrant	Tristar	Soakage

2.2 Color characteristics measurement

According to ISO 13655 [6], a spectrophotometer (X·Rite-i1 pro2) (with D50 illumination and an observer angle of 2°) was employed to measure the surface colors of the test plates, and the measured values of L*, a*, b*, c*, h* and the spectrum were saved in a text file. In these data, L* denotes brightness, a* indicates red-green transition and b* refers to yellow-blue transition, and red or yellow are indicated by positive values, green or blue are represented by negative values. The range of L* is 0 to 100 (black-white), and it of a* and b* are -128 to +127. The saturation (c*) can increase from 0 to 100, and the hue (h°) corresponds to a certain angle (0° - 360°) [7]. Due to the addition of a fluorescent agent in Visijet PXL powder, test results obtained from the M1 condition of the spectrophotometer were used for the following calculations [8]. The chromatic aberration formula was adopted to calculate the values of luminance difference (ΔL), saturation difference (ΔC), hue difference (ΔH), and ΔE2000 (CIEDE 2000, equation (1)) [9].

2.3 Color characteristics and structure trials of multiple faces

Following the printing and processing method above, four primary-color 3D-printed cubic models were processed by two best methods selected after evaluating all four of the impregnating methods. The opposite faces of the printed cubes were analogous due to the same moulding mechanism; therefore, the planes, which were adjacent to each other, were separately measured five times (at four corners as well as at the center) to simplify measurement processes and reduce the errors that originated from single-point sampling.

3. Results and discussion

3.1 Color optimization effect of single face

After the completion of impregnating treatment, surface colors of the test samples were optimized obviously as the overall color reproduction shown in Figure 1.

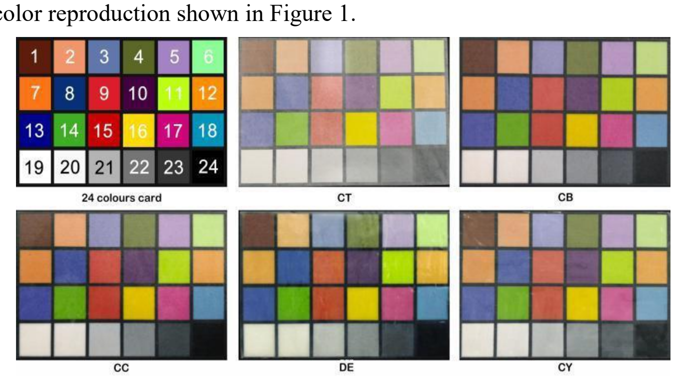

Fig.1 24 colors card and five impregnated test plates

3.1.1 Variation of brightness and saturation of impregnated 24-Color Plates

The scatter of luminance-saturation points of standard values as well as measurements in 5 groups was shown in Figure 2. The measured values of the original sample were consistent with the results of influencing factors except for a few colors with high brightness. The brightness of all of the other colors was higher than that of the standard card; however, their saturation was reduced. However, the effects of Clear Coat on CC group were just the opposite to the expected results. When Clear Coat was sprayed on the test plate, the brightness of all of the colors increased significantly; however, it started to decrease after drying and reached a value lower than that of CB group sample without Clear Coat. In addition, the saturation of the CC group sample increased greatly due to the absorption of Clear Coat into the substrate. The brightness of the CY group sample after impregnation was excellent for the reproduction of certain high-brightness colors, which indicates that the color saturation can be optimized without reducing the brightness. Overall, the addition of impregnant expands the color reproduction range of the powder-based model, especially in CC group, which increases the ability of multi-color and high- fidelity reproduction.

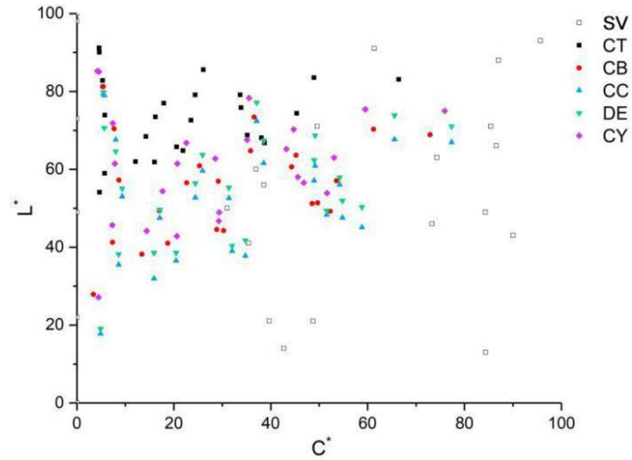

Fig.2 Brightness-saturation scatter diagram. SV, standard value.

3.1.2 Variation of chromatic aberration of impregnated 24-Color Plates

The calculated chromatic aberration of each group was shown in Figure 3. The decrease in brightness caused by the impregnating process increased the chromatic aberrations of some high brightness colors to some extent, such as No. 6, 16, 19 and 20. The measured value of the last six gray-scale color blocks reflected that when the brightness of the color is lower than 73, the optimization characteristic of the impregnating process is the main factor. In addition, the lower the brightness and the higher the saturation, the better the optimization effect after impregnating process, such as No. 8, 10 and 13. After the combination of ColorBond and transparent coating spray (CC), the chromatic aberrations of most color blocks was the smallest among the four groups, and the two-component epoxy resin coating method (DE) also greatly reduced the chromatic aberration, but due to the heterogeneity of manual coating, the trend in DE group appeared deviation, for example, the brightness of No. 20 was only 2 lower than that of No. 19, but the measured chromatic aberration were obviously different.

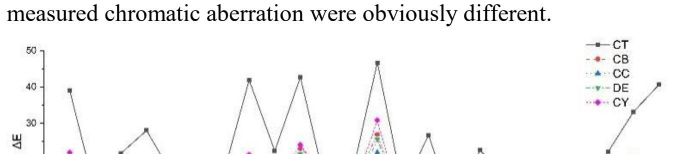

Fig.3 Chromatic aberration curves of test plates in five groups

Finally, the average values, ranges and standard deviations of chromatic aberrations of 24 color blocks in each group were calculated by statistical method (Figure 4). It can be seen that the combination of ColorBond and transparent coating spray is the most suitable impregnation method for powder-based 3D printing, and many surface colors with poor reproducibility have been optimized. If the coating uniformity is improved and the coating thickness is controlled, epoxy resin coating is also a good impregnating method.

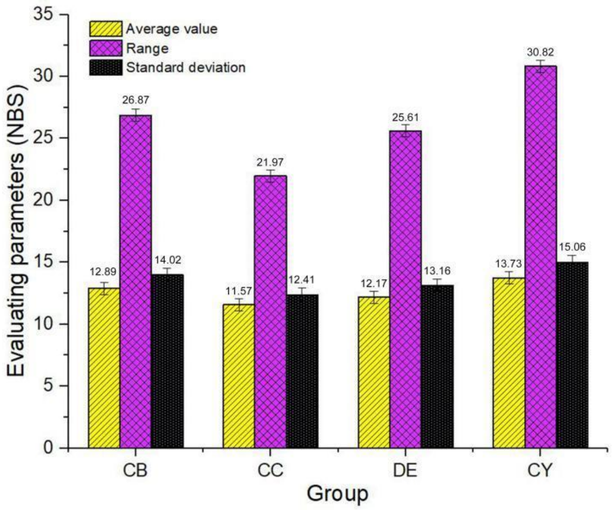

Fig.4 Average value, range and standard deviation of chromatic aberration of impregnated plates

3.2 Color optimization effect of multiple face

The measured color data of all of the test cubes are illustrated in Figure 6. It is evident that except for yellow cube, post-processing significantly reduced the chromatic aberration in all other cubes (Figure 6(c)). As the human eye visual results in Figure 5, the samples not subjected to the impregnation were not only in poor condition of the single-face color reproduction, but also showed significant differences in the color between the different faces. The processing method of CC group optimised the surface colors as well as reduced the color aberration in different faces of all of the cubes. Moreover, a profound disparity in color was observed on different faces of cyan, magenta, and yellow cubes coated with epoxy resin; however, the optimization of chroma was the best among all three of the groups. The amelioration of chromatic aberration in the black cube was excellent, the value of average chromatic aberration of three faces decreased from 34.4 to 12.2 with a reduction in maximum ΔE of two faces from 8.12 to 0.82. Therefore, the simple post-processing method that combines ColorBond and Clear Coat is the most suitable technique for powder-based 3D printing, and the post-processing method of DE group could also be a viable way to reduce chromatic aberration.

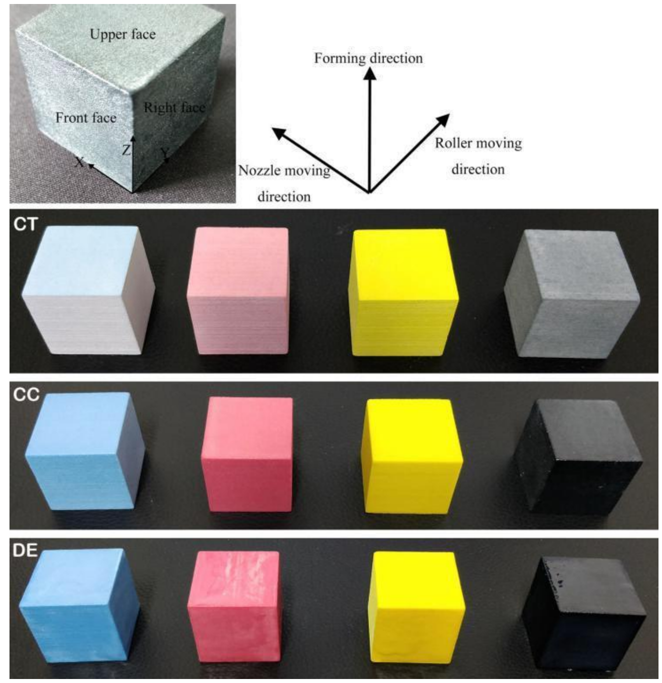

Fig.5 Four impregnated primary color cubes in three groups

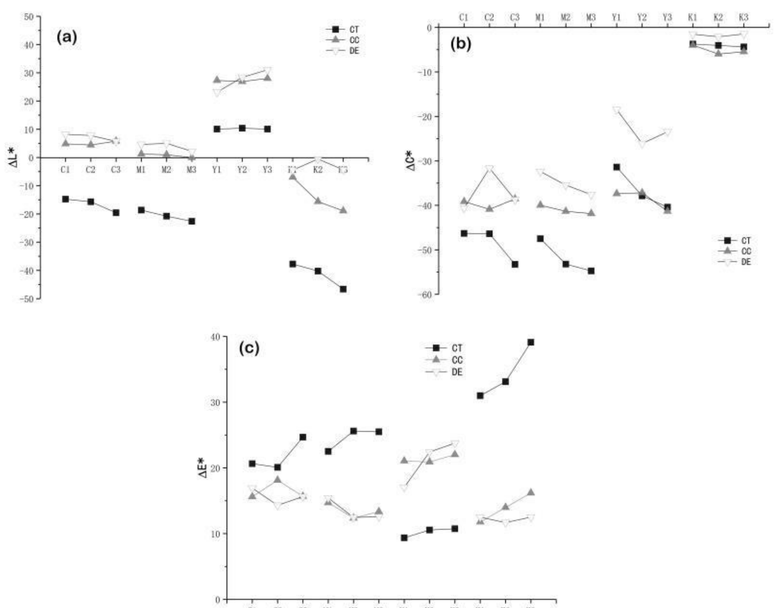

Figure 6. Measured color data of all test cubes: (a) ΔL (Lb-Ls*) of colors, (b) ΔC (Cs*-Cb*) of colors, (c) ΔE of colors. X-axes labels: (C) Cyan cubes, (M) Magenta cubes, (Y) Yellow cubes, (K) Black cubes, (1) Upper face of cubes, (2) Front face of cubes, (3) Right face of cubes. The subscript 's' represents the standard color data, and 'b' represents the color measured data.*

4. Conclusions

Based on different impregnation parameters of five test groups (CT, CB, CC, DE, and CY), color characteristics of all the 3D-printed samples were analyzed. Thus, the relationship between them and the direction of color reproduction accuracy promotion were obtained. The results showed that chromatic aberration between surface color and target color decreased significantly in all four of the post-processing methods with the increasement of saturation as well as the decreasement of brightness. Furthermore, enhancement of coating uniformity, transparency and permeability effectively increased the accuracy of color reproduction. Hence, these factors could be used as a guide to select better impregnants for improving the post-processing method. Moreover, the combination of ColorBond and Clear Coat greatly reduced the chromatic aberration among the same colors on different faces of the samples.

In order to expand the application of 3D Printing and enrich surface information of 3D printed models, full-color 3D printing is an overall trend of various 3D printing technique in the future. The color optimization technology of planar inkjet printing cannot be directly applied to 3D objects. Therefore, this paper analyzed the 3D surface color mechanism and compared the optimization results of different impregnation methods to improve the color reproduction accuracy of full-color 3d printing effectively and expand the color gamut range.

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