Preliminary study for transparentization of SLS parts by resin infiltration

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Abstract

Since opacity of SLS processed parts are derived from random reflection and refraction at boundaries of refractive indices between the air and plastic, infiltration of resin that shares the same index with the plastic can increase transparency of the parts. In this paper, desirable characteristics for the infiltrant were investigated first, and transparentization test of SLS processed parts out of CastForm™ was carried out. The highest transmittance of 80% and the lowest haze of 55% were obtained. However, exact match of refractive indices of powder for SLS and infiltrant did not give the best transparency. The reasons were considered in discussions.

Introduction

As for building accuracy and ability of building fine structure, selective laser sintering (SLS) is inferior to stereolithography (SL). However, it is superior in terms of large options of materials such as variety of thermoplastics, some metals and ceramics. Owing to this advantage, typical SLS processed parts out of PA or its glass-filled version are stronger and tougher against heat than SL processed parts out of cured photoresin. Therefore, SLS is better choice for the purpose of evaluating mechanical property of a prototype part whose tolerance and dimension of its finest structure are larger than 0.2mm and 1mm, respectively. However, SLS is not suitable for fabrication of displays showing both of their external and internal structures because of inevitable opacity of the parts build by the process. This paper introduces a postprocess that can transparentize an SLS processed part by infiltrating a resin with tuned refractive index and reports some experimental results of transparentization of SLS processed parts out of polystyrene.

Transparentization Method and Process

Figure 1a depicts behavior of a ray of light incident into an SLS processed part out of transparent material. As shown in this figure, SLS processed parts are always porous, and there are many boundaries between plastic and the air. Since the refractive index of plastic is greater than that of the air, the SLS processed part is filled with many boundaries of refractive indices. When a ray of light meets such a boundary, the ray will refract or reflects in many cases. As a result of random refraction and reflection at the boundaries, the light is scattered while it passes through the parts. There are two ways to prevent these phenomena. One is to use smaller powder than wavelength of visible light, and the other is to unify the refractive indices in SLS processed parts.

Currently, particle diameter of powder for SLS is more than 10 μm, which is much greater than wavelength of visible light. Accordingly, the way by unification of refractive index in the processed parts is selected. More concretely, a liquid resin that can be cured afterward and of which refractive index after being cured is tuned to that of powder is infiltrated into the porous parts to unify the refractive indices as shown in Figure 1b. Currently, similar technique is utilized to transparentize ABS or glass filled epoxy composite. In transparentization of ABS, refractive index of SAN copolymer is tuned to that of butadiene by adjusting the ratio of styrene and acrylonitrile [1]. In the case of the composite, refractive index of epoxy resin as matrix is tuned to that of the glass filler [2].

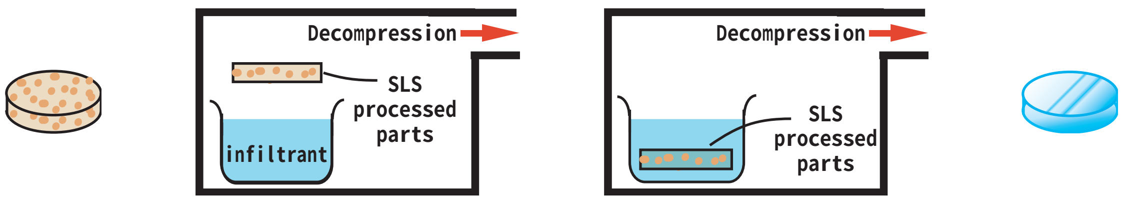
In addition, technique of liquid resin infiltration into SLS parts has been widely used to improve strength of SLS processed parts.

a. The path of ray inside of SLS processed parts

b. The path of ray inside of SLS processed parts infiltrated with resin whose refractive index is close to SLS resin

Figure 1: Difference of the path of ray between a and b

Figure 2 shows transparentizing process of SLS processed parts. Firstly, the original parts are loaded into vacuum chamber to remove the air from pores of the part (b), then the parts are dipped into the resin with tuned refractive index, and the pores are filled with the resin instead(c). The parts are unloaded out of the chamber and the infiltrant is cured.



a. SLS processed parts

b. Decompression of chamber in which SLS processed parts are put

c. Resin infiltration into SLS processed parts under decompression

d. Cure of infiltrant

Figure 2 : Transparentization Process from SLS processed parts

Experiments

Transparentization test of an SLS processed parts out of CastForm^{TM} (CastForm parts after that) was carried out to confirm effectiveness and limitation of the process. Before testing the SLS processed parts, preliminary tests using several types of commercially available resins and dummy parts of powdery AS copolymers with various refractive indices were carried out. The reasons why the preliminary tests were performed are as following:

1. A curable resin whose refractive index is the same as that of CastForm^{TM} is not commercially available.
2. To develop such resin takes a lot of cost and time.
3. Contrarily, various powders of AS copolymer with different refractive indices can be obtained more easily.
4. Some characteristics other than refractive index after being cured must be found to develop the resin.

<u>Preliminary test using AS sinters</u>

Table 1, 2 summarizes properties of powders and resins used in the experiments described in this section. Since it is difficult to find exact SLS process parameters out of various AS powders, dummy parts were fabricated by sintering powder in a mold as shown in Figure 3. When an acrylate monomer with a viscosity of 70cps (resin A) was infiltrated into a specimen of uncrosslinked AS (specimen A), the sinter was dissolved as shown in Figure 4a. Secondly, an acrylate monomer with a viscosity of 435cps (resin B) was infiltrated into the specimen (specimen A), and the sinter was also dissolved. Then, epoxy with a viscosity of 40cps (resin C) was tested. The resin also dissolved the part. Finally, an epoxy resin D whose viscosity was 140cps was infiltrated, and this time, the structure of the part remained successfully as shown in Figure 4b. Figure 4c shows a part (specimen B) infiltrated with the epoxy (resin C). This time, the shape was maintained because of crosslinkage of the polymer. In addition, the specimen was successfully transparentized. The results of preliminary test were summarized in Table 3.

These experiments give following suggestions:

1. epoxy is suitable as an infiltrant
2. viscosity of infiltrant is desirably higher than 140cps
3. matching refractive indices can give transparency to porous sinter

Table1： Physical Properties of AS Sinters

	Specimen A	Specimen B
Crosslinkage	Uncrosslinked AS	Crosslinked AS
Refractive Index	1.54	1.52
Particle Diameter(mm)	40	50

Table2： Physical Properties of Resins Infiltrating into AS Sinters

	Resin A	Resin B	Resin C	Resin D
Material type	Acrylate	Acrylate	Epoxy	Epoxy
Refractive Index after curing	1.54	1.49	1.51	Non Data
Viscosity at 25℃ (cps)	70	435	40	140

Figure3: An AS sinter

a. Specimen A infiltrated with resin A | b. Specimen A infiltrated with resin D | c. Specimen B infiltrated With resin C

Figure4: Infiltration of resins into AS sinters

Table3：Summery of preliminary test

	Specimen A	Specimen B
Resin A	□	□
Resin B	□	□
Resin C	□	○
Resin D	○	○

□…Impossible to keep the shape of AS sinters ○…Possible to keep the shape of AS sinters

Transparentization of CastForm parts

Specimens out of CastForm^{TM} were built with Vanguard HS as shown in Figure 5. Figure 6 shows dimensions of the specimen. Refractive index of CastForm^{TM} was obtained as 1.588 by measuring a cubic bulk of CastForm^{TM} that are fabricated by melting its powder and cutting after being cooled.

Five UV curable epoxies whose refractive indices are listed in Table 5 were used as infiltrant in transparentization test. To obtain the resins with the different refractive indices, two resins of which indices are 1.579 and 1.590 were prepared first, and then they were mixed in different ratios to vary the indices of the mixtures. The indices displayed in the table for infiltrant B, C and D were obtained by simple linear calculation of the blending ratio and the refractive indices of the two original resins. Viscosity of the resin is greater than 140cps for each.

Figure5: CastForm part

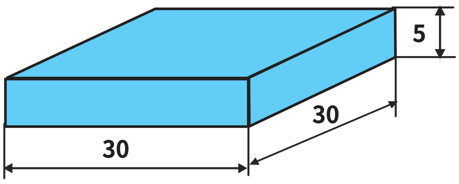


Figure6: Dimension of CastForm parts

Table4: Physical properties of CastForm^{TM}

Refractive index	Particle diameter(μm)
1.588	62

Table5：Physical properties of UV-curable epoxy infiltrating into CastForm parts

	Infiltrant A	Infiltrant B	Infiltrant C	Infiltrant D	Infiltrant E
Refractive index after cure	1.579	1.582	1.585	1.588	1.590

※All UV-curable epoxy resins have a viscosity of more than 140cps at 25℃.

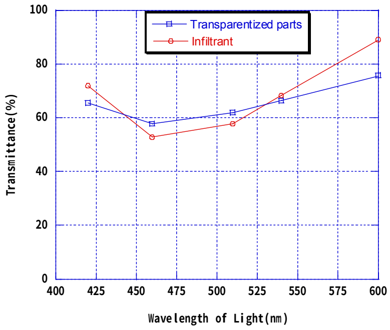
Results of transparentization by infiltrating infiltrant A-E are shown in Table 6. Here, alphabetic index of each obtained test piece is corresponding that for its infiltrant. As a result of this transparentization, it became possible to read the characters below the parts clearly. However, all of the parts colored into yellow or orange. The highest transmittance was 80%, and the lowest haze was 55% in the case of part (B).

Diagrams in Figure 7 display results of transmittance measurements at wavelengths of 420, 460, 510, 540 and 600nm for the transparentized parts and the infiltrants. As shown here, relationship between transmittance and wavelength for the infiltrated parts and that of infiltrants agree very well. This result displays that coloring of the transparentized parts is caused mainly by that of infiltrant.

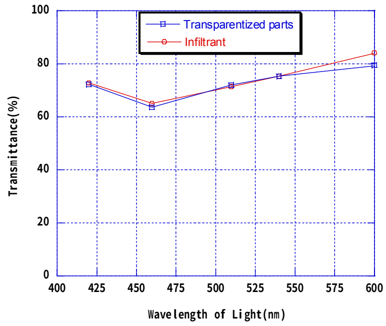
Table 6：Transparentized parts out of CastForm parts. Transmittance and haze were measured by following the procedure defined by ISO13468 and 14782, respectively. For measurements of transmittances, red light with a wavelength of 600nm was used. For measurements of hazes, white light was used.

Transparentized parts	Difference in refractive indices of powder and infiltrant	Picture of transparentized parts put on the paper	Transmittance (%)	Haze (%)
Part (A)	-0.009		74.3	85.1
Part (B)	-0.006		79.5	55.1
Part (C)	-0.003		42.4	91.4

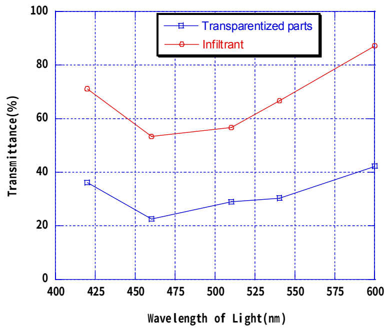
Part (D)	0		61.2	87.5
Part (E)	0.002		59.8	90.3



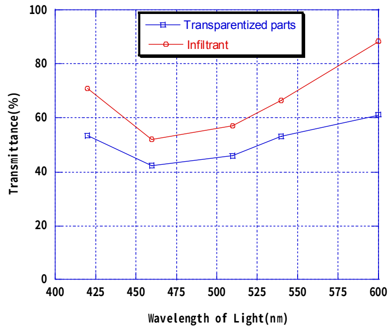
a. Part (A)



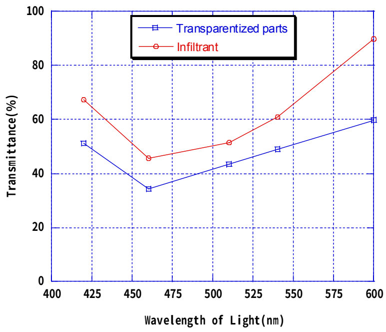
b. Part (B)



c. Part (C)



d. Part (D)



e. Part (E)

Figure 7: Ttransmittance measurements of transparentized parts and that of Infiltrant resin alone

As found in the photographs in the Table 6, transmittance, haze and color are not uniform over a whole surface of each test piece. Figure 8 and 9 show transmittances and hazes measured at the centers and near the edges of the transparentized parts, respectively. According to these measurements, transparentization was more successful near the edge than at the center in terms of both of transmittance and clarity for the most cases. These nonuniformities seem to derive from nonuniformity of UV irradiation in curing process. In the process, a UV lamp was set at 20cm above the center of infiltrated specimen. Since the light source was a spot light equipped with focusing lens, irradiation is stronger at the center than the edge. Resultantly, resin near the edge was cured insufficiently.

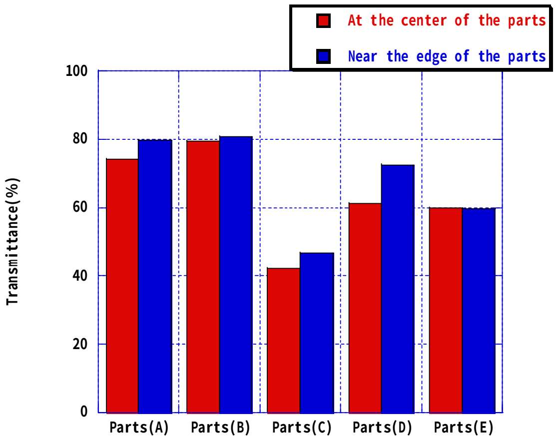


Figure 8: Transmittance at the center and near the edge of the transparentized parts. In these measurements, light with a wavelength of 600nm was used.

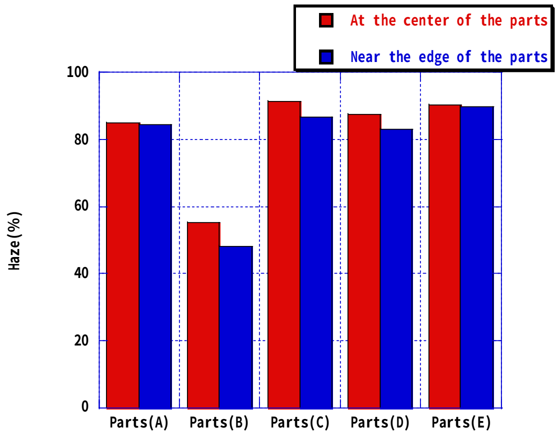


Figure 9: Haze at the center and near the edge of the transparentized parts

Discussions

As found in Table 6, exact match of refractive indices of powder and infiltrant did not give the best transmittance or clarity. The reasons why the transparentized part is still hazy even if the exact match of the refractive index was given are considered as following:

1. Cured infiltrant is hazy

Infiltration into CastForm sinter degraded exposing condition of the infiltrant, and, as result, it created islands-sea structure as depicted in Figure 10. Since difference between the refractive index of the cured infiltrant and that of procured is approximately 0.02, the matrix, i.e. cured infiltrant, itself becomes hazy if there is such structure and its dimension is greater than the wavelength of visible light.

2. Grain composing the parts is hazy

In the process of building a part, melting and solidify by laser exposure might have crystallized each grain of the powder.

3. Refractive index of the grain lowered

When CastForm parts were infiltrated, photocurable epoxy soaked into the powder and refractive index of CastForm^{TM} was lowered.

The experimental results obtained in this research do not demonstrate which reason is the most dominating clearly. However, we can conclude that there are some ways to improve the transparency by changing the infiltrant, if the main reason exists in infiltrant. On the other hand, if the haze derives from the SLS process itself, it may be difficult to obtain better transparency.

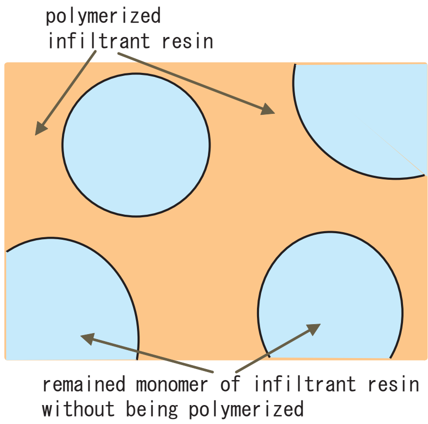


Figure 10: Schematic view of island-sea structure

Conclusions

An SLS processed part of CastForm™ was successfully transparentized by infiltrating a photocurable epoxy whose refractive index is tuned to be the same as that of CastForm™. The transmittance for test piece with thickness of 5mm reached the highest value of 80% making it possible to read characters below the test piece. The refractive index that gives the maximum transmittance is lower than expected by 0.006. After this process, a haze of 55% still remained at minimum. The reason for this remaining haze was not clearly demonstrated, but it can be reduced if the problem derives from haze of infiltrant.

References

[1]. K. Chiba, “Refractive Index Control of Transparent High Polymers”, Survey of Chemical, No.39, 1998

[2].H. Sato, H. Iba, T. Naganuma, and Y. Kagawa, ”Effects of the Difference between the Refractive Indices of Constituent Materials on the Light Transmittance of Glass-Particle-Dispersed Epoxy-Matrix Optical Composites”, Philosophical Magazine B, Vol. 82, No. 13, p.p.1369-1386, 2002