Shrinkage Predication of Human Tooth Manufactured Through 3D Printing

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***Abstract*—The traditional dental prostheses components often need to be molded by the plaster, it makes the patients uncomfortable. After the mold is taken from the patient's mouth, it then be used as the coarse mold for further casting and sintering. The shape is then modified by CNC machining to fit the patient. However, it is difficult to confirm adaptation of tooth installed in patient's mouth. If adaptation of tooth is not suitable, the tooth will be taken out soon. The reason is that the teeth are decayed again in the future and cause bad breath. The above steps are not only time-consuming, high cost, but also easily cause patient's discomfort and medical problems. The 3D printing method for the human teeth is another choose of the manufacture. CAE analysis and experimental design investigated here could be applied to predict shrinkage of different dentures shape. Then the dentures shape can be reversed amplifier. It will be close to patient requirement who needs the precise dentures shape, also it can avoid complicated procedure of CNC machining and reduce dentists finishing time.**

***Index Terms*—3D printing, Tooth, CAE analysis.**

I. Introduction

Nowadays, 3D printing technology is becoming maturate, and many people try to apply it on variety of use. 3D printing includes a lot of types, such as Stereo Litho-raphy Apparatus (SLA), Fused Deposition Modeling (FDM), Laminated Object Manufacturing (LOM), Selective Laser Sintering (SLS), Laser Engineered Net Shaping (LENS) and Digital Light Processing (DLP) etc. The DLP method is used in this paper, because the components of DLP are cheap and easily to get. In [1], the DLP-system was used to create a ceramic green part by stacking up layers of a photo-curable resin with a solid loading of around 45 vol.% zirconia. After a thermal debinding and sintering step, the part turns into a dense ceramic and gains its final properties. Althought dentures were made by plaster which is the most common method in traditional of density. 3D printing is developing as another approaching on dentures, and the shrinkage of tooth will be different according to different prescription. The results obtained in this paper could offord the reference to different detures when the prescription is changed. Yau [2] proposed a full tooth reconstruction method by integrating 3D scanner data and computed tomography (CT) image sets to reconstruct a high quality customized dental model. The model can offer significant help to the planning of dental implant and orthodontic treatment. In [3], a comprehensive study of the design and 3-dimensional (3D) printing of the customized implants is investigated. The mechanical properties and their biomechanical behavior are not included. Martorelli [4] informed that a well-accepted technology 3D printing today is to fabricate orthodontic aligners by using the thermoforming process, instead the potential of CNC systems in dentistry have not yet been sufficiently explored. In [5] recent developments in cone beam CT and rapid 3D prototyping have enabled the fabrication of accurate surgical templates which can be used to prepare the recipient site immediately prior to transplantation. This has resulted in a drastically reduced extra-oral time for the transplant teeth which can be expected to improve success rates further. Tamimi [6] demonstrated that it is possible to achieve osseointegration of dental implants in bone augmented with 3D-printed synthetic onlays. In [7] with image processing techniques, the intraoral surface data is acquired by an intraoral scanner and radiologic 3D data. In this paper, the test blocks are manufactured by 3D printing firstly, and then be sintered. The rapid prototyping technologies can construct physical models from computer-aided design via 3-dimensional (3D) printers [8]. A prefabricated 3D model is achieved, which assists in accurate contouring of plates and/or planning of bone graft harvest geometry before surgery. The two most commonly used methog of rapid prototyping technologies are stereolithography and 3D printing (3DP). 3DP is more accurate than stereolithography, quicker printing time, and lower cost. There was a revolution occurring in developing 3D printable materials. Which aims to cover the range of material properties needed for patient-specific implants to either resorb at an appropriate time or perform mechanically, like the tissues to which they were attached [9]. As advances are made in bone, retina, teeth, and other areas of craniofacial and dental tissue engineering, they are likely to be incorporated into

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standard-of-care therapies. Hung [10], *et al*. proposed an approach that combine cells, scaffolds, and stimulatory cues hold considerable potential for regenerating functional bone. Several modalities are suited to generating scaffolds with the complex anatomical geometries of the craniofacial bones. Of these, 3DP is particularly attractive as it is capable of providing precise control over both the macroscopic and microscopic architecture of the scaffold. The shrinkage rate is then obtained for the CAE simulation. Then the shrinkage rate of volume is obtained. Finally, the model site of the tooth is magnified according to the experiments and simulations. After the replacement part of human tooth is manufactured by 3D printing, the sintered prosthesis then can be put in standard tooth mold.

II. 3D Printing and Predicted Shrinkage of Specimen

Several parameters and dimensions of different standard specimen are used for experiment of sintering. At the beginning, zirconia is pulverized by using ball grinder. Resin and hardener take powder to print out standard specimen. Then they are put in high-temperature sintering furnace to sinter with temperature range from 25° to 1350°. The shrinkage of 3D printing is shown in Fig. 1 and Fig. 2. In the measurement, each specimen was measured five times and mean value is obtained. The relationship of shrinkage and dimension can be represented in Tables I to IV. According to the results of experiments, they can be referenced for parameters setting and simulation of CAE.

Figure 1. Dimension of specimen before sintering.

Figure 2. Dimension of specimen after sintering.

TABLE I. Difference before and after Shrinkage of Test 1.

Test 1	Length	Width	Thickness	Volume
Before Sintering	17.553mm	8.594mm	1.161mm	175.13mm^3
After Sintering	13.573mm	6.648mm	0.898mm	81.03mm^3
Shrinkage Rate	22.674%	22.643%	22.652%	53.733%

TABLE II. Difference before and after Shrinkage of Test 2.

Test 2	Length	Width	Thickness	Volume
Before Sintering	17.553mm	8.594mm	2.35mm	357.58mm^3
After Sintering	13.573mm	6.656mm	1.818mm	165.42mm^3
Shrinkage Rate	22.685%	22.649%	22.648%	53.737%

TABLE III. Difference before and after Shrinkage of Test 3.

Test 3	Length	Width	Thickness	Volume
Before Sintering	17.576mm	8.583mm	3.737mm	563.74mm^3
After Sintering	13.591mm	6.638mm	2.891mm	260.81mm^3
Shrinkage Rate	22.671%	22.65%	22.658%	53.734%

TABLE IV. Difference before and after Shrinkage of Test 4.

Test 4	Length	Width	Thickness	Volume
Before Sintering	17.584mm	8.601mm	4.718mm	713.55mm^3
After Sintering	13.596mm	6.653mm	3.649mm	330.06mm^3
Shrinkage Rate	22.676%	22.647%	22.661%	53.742%

After sintering forecast, average shrinkage rate is taken from four experiments. The results show that the shrinkage of Length (X axis) is 22.677%, Width (Z axis) is 22.647%, and the Thickness (Y axis) is 22.655%.

III. Parameters Setting and CAE Simulation

After the experiments are proceeded, the shrinkage of each side was obtained and the model was created by SolidWorks whose dimension is 17.553 × 8.594 × 1.161 (mm) as shown in Fig. 3 (the dimension of Test 1). And then the model was simulated in Ansys Static Structural. After several simulations, the volume of shrinkage rate is similar to experiment result which is 53.737% as shown in Table V. The results show the original model need to be magnified 1.861 times.

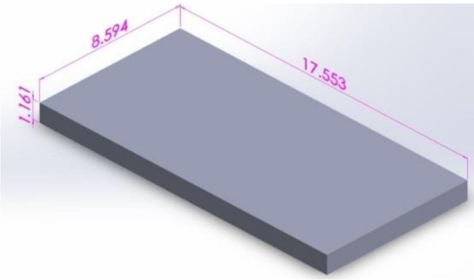

Figure 3. The dimension of model.

TABLE V. THE VOLUME OF SHRINKAGE RATE

Simulation	Length	Width	Thickness	Volume
Before Simulating	17.553mm	8.594mm	1.161mm	175.13mm^3
After Simulating	13.572mm	6.648mm	0.898mm	81.024mm^3
Shrinkage Rate	22.68%	22.644%	22.653%	53.737%

Parameters were set in ANSYS as shown in Fig. 4, and the sintering temperature of model was set from 1350 ℃ to 25 ℃ in boundary condition for the simulation of sintering. As shown in Fig. 5, point A is fixed, while point B and C are free due to the shrinkage.

Orthotropic Secant Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion		
Coefficient of Thermal Expansion X direction	0.00019415	C^-1
Coefficient of Thermal Expansion Y direction	0.0001935	C^-1
Coefficient of Thermal Expansion Z direction	0.00019375	C^-1
Reference Temperature	22	C

Figure 4. The parameters set in ANSYS

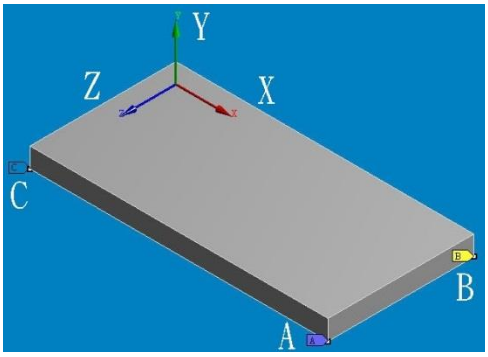

Figure 5. The boundary condition of model

IV. SRINKAGE SIMULATION OF TOOTH

The CAE method of tooth was converted from STL to IGES file by Pro Engineer. Then the file was magnified 1.861 times by SolidWorks according to the results of specimen, and gridded by Altair HyperMesh as shown in Fig. 6. Then the model is imported to Ansys APDL and wrote in a file which can be used by Ansys WorkBench. Finally, the file was imported in Finite Element Modeler (FEM) and coupled with Static Structural in Ansys WorkBench, then simulation is proceeded and the result as shown in Fig. 7.

After the simulation, shrinkage rate of the tooth is 53.71% as shown in Table VI. Then the tooth was magnified 1.861 times for the manufacture of 3D printing and sintered, the result shows that the experiment is workable as shown in Fig. 8 to Fig. 12.

TABLE VI. SHRINKAGE OF THE TOOTH

Simulation	Volume
Before Simulation	1008.3mm^3
After Simulation	466.744mm^3
Shrinkage Rate	53.71%

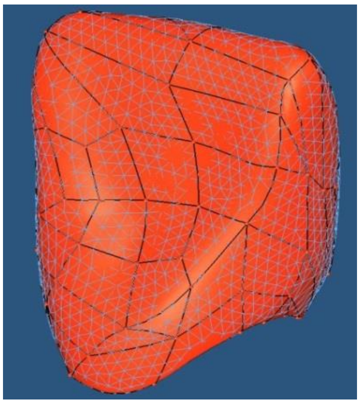

Figure 6. The model was meshed by Altair HyperMesh.

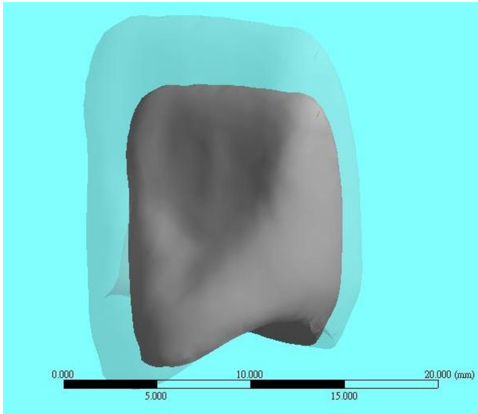

Figure 7. Before and after simulation of tooth in ANSYS, and the shadow was before simulation.

Figure 8. The teeth were printed and magnified 1.861 times

Figure 9. The teeth were sintered

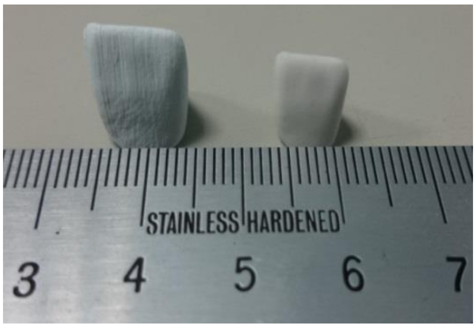

Figure 10. The tooth was magnified 1.861 times, before and after sintered.

Figure 11. The standard tooth mold.

Figure 12. The result is displayed to indicate the experiment is workable.

V. CONCLUSION

In this paper, the shrinkage of human tooth is studied by simulation and experiments. In the study, the shrinkage rate is about 53% for the specimen manufactured by 3D printing. The shrinkage rate is then successfully applied in the manufacture of human tooth by 3D printing. The workpiece is then sintered and set in the human mouth successfully. The results in this paper are useful to build the model for the 3D printing and sintering.

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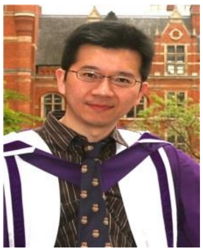

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