OPTIMIZATION OF SCALE FACTORS IN SHRINKAGE COMPENSATIONS IN SLS USING PATTERN SEARCH TOOL AND GENETIC ALGORITHM

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Abstract— **This paper presents new approach for shrinkage compensation in Selective Laser Sintering (SLS) process to improve the accuracy of parts produced. By optimizing tools like Pattern search tool and Genetic algorithm available in MATLAB 2011. Shrinkage is compensated along X, Y, Z direction of the part produced. The scaling factor used in this compensation is calculated from shrinkage model (It is the empirical relation between percentage shrinkage and the machine manufacturer, Shrinkage model). Software is available in MATLAB 2011, automate the compensation process. Two case studies were presented to quantify the effectiveness of the developed compensation approach over the existing compensation method. From the comparison experiments, the ability of the proposed compensation method in improving the accuracy of laser sintered parts is established..**

Index Terms— **Selective laser Sintering; Shrinkage; Dimension accuracy; MATLAB2011**

I. Introduction

Selective laser sintering (SLS) is a layered manufacturing process that builds the prototypes by selective sintering of material in the powder form, like thermoplastic polymer powder (Polyamide 2200), using a CO2 laser. Prototypes made by SLS process are widely used in product development as discussed in the application part of this chapter, and therefore should have a very good surface finish for functional performance as well as aesthetics. However the prototypes made by the SLS process have comparatively high surface roughness due to the stair stepping effect. Surface roughness of the prototypes also depend on the various process parameters such as build orientation, laser power, layer thickness, beam speed and hatch spacing. Majority of its applications are in aerospace and rapid tooling, where high accuracy levels have to be met in order to ensure proper functional requirements.

Shrinkage is defined as change in dimension of the sample which occurs due to the change in volume of sample. It mainly occurs due to the part bed temperature and physical changes occur due to the increase in the energy density when the powder material is sintered and solidified. And compensate shrinkage, to match up with the accuracy of the original STL file suitable scale factor are needed to be given so that accurate dimension of sample or proto type can be obtain.

II. DEVELOPMENT OF SHRINKAGE MODEL

A. Nature of shrinkage

It is interesting to note that shrinkage factors are not constant value but it varies according to the geometry in many RP processes. Moreover, there is a directional effect considering the direction in which laser scanning takes place and the direction perpendicular to it. In this work, an attempt is made to study the effect of geometry i.e. scan length on shrinkage in the direction of the laser scanning. The non-uniform shrinkage compensation applies different shrinkage values at different portion of the geometry. Uniform shrinkage compensation changes only the size of the part whereas a non-uniform Compensation will change the size and shape of the part as shown in Fig. 1.[By K Senthilkumaran, P M Pandey and P V M Rao]

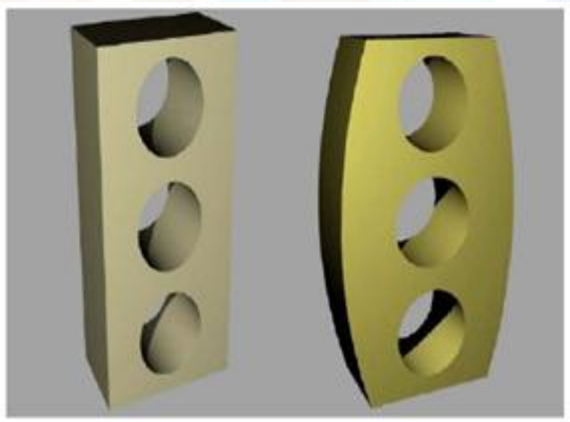

Fig. 1 Change of size and shape in non-uniform shrinkage compensation,

B. Empirical model Derivation

Empirical models are derived by linear regression using standard statistical software. The developed models predict the shrinkage (%) for any set of parameters to scale up the STL file for better accuracy. These scaling factors (S_X, S_Y and S_Z in %) to compensate shrinkage along X, Y and Z directions are as given below,

$$S_X = 1.61191 - 0.01615Lp - 0.00964Lc$$
$$S_Y = 0.785926 - 0.032656Lp + 0.000281Bs$$

S_Z = -28.6238 + 0.000308Bs + 4.0417Hs + 0.16792TB + 31.04

where, Lp is the laser power in watt, Bs is the beam speed in mm/sec, Hs is the hatch spacing in mm, TB is the part bed temperature in 0C and Lc is the scan length in mm. In the present work, most of the process parameters are kept constant except scan length.

III. CASE STUDIES

The shrinkage compensation algorithm and the developed shrinkage models are verified by conducting experiments. Improvement in accuracy is studied by following two different compensation methods:

-- First using a constant shrinkage scaling factor (prescribed by RP machine manufacturer) in one part

-- Second using the shrinkage model and new shrinkage compensation system in another part.

[By K Senthilkumaran, P M Pandey and P V M Rao]

Hence it is observed that dimensional accuracy improves along the scan direction due to new compensation approach.

Table 1 Process parameter used in case studies [By K Senthilkumaran, P M Pandey and P V M Rao]

Parameters	**Shrinkage Model**	**Machine Manufacturer suggested compensation**
Laser power(w)	36	36
Beam Speed (mm/s)	4500	4500
Hatch Spacing (mm)	0.3	0.3
Part bed temperature (^{0}C)	175	175
Shrinkage along X (%)	1.0303-0.009647 L_c	0.43
Shrinkage along Y (%)	0.880784	0.58
Shrinkage along Z (%)	3.361	3.5

Table 1 Process parameter used in case studies

D. These case studies solve by MATLAB 2011 by using the optimizing tool Pattern search method and Genetic Algorithm.

To analyze the empirical models represented by equation for predicting the optimum value of shrinkage percentage using MATLAB2011 in selective laser sintering (SLS). To obtain set of parameters which is the function of the shrinkage percentage namely laser power, scan length, part bed temperature, beam speed, hatch spacing, to give optimum shrinkage value by using Taguchi method in selective laser sintering (SLS).To determine the optimum values of shrinkage in X-direction, Y-direction and Z-direction, using Taguchi method in selective laser sintering (SLS).To determine the optimum values of Laser Power [Lp], Scan length [Lc], Hatch spacing [Hs], Part bed temperature [Tb] and Beam speed [Bs], using MATLAB in selective laser sintering (SLS). To compare the results obtained for optimum value of shrinkage percentage and Machine manufacturer's values by Pattern search method and Genetic Algorithm.

Shrinkage along the X-direction;

Minimize (SX) = 1.61191 - 0.01615Lp – 0.009647 Lc

Where Lp = Laser Power (in Watt), Lc = Scan Length (mm)

Subject to the condition that

Shrinkage along the Y-direction;

$$0 \le L_c \le 75$$

Minimize (S_Y) = 0.785926 – 0.032656 L_p + 0.000281B_S

Where B_S = Beam speed

Subject to the condition that

$$25 \le L_p \le 36$$

Shrinkage along the Z-direction;

$$2500 \le B_S \le 4500$$

Minimize (S_Z) = -28.6238 + 0.000308 B_S + 4.0417 H_s + 0.16792 T_b + 31.04

Where H_S = Hatch Spacing, T_b = Part Bed Temperature

Subject to the condition that

$$2500 \le B_S \le 4500$$
$$0 \le H_S \le 0.3$$
$$100 \le T_b \le 175$$

IV. RESULT COMPARE WITH, K SENTHILKUMARAN, P.V.M RAO;

Parameters	**Shrinkage Model**	**Machine Manufacturer Suggested Compensation**	**By using Pattern search Tool in MATLAB 2011**	**By using Genetic Algorithm in MATLAB 2011**
Laser Power (w)	36	36	36	36
Part Bet Temperature (^{0}C)	175	175	175	175
Scan Length (mm)	75	75	75	75

Shrinkage along X (%)	1.0303-0.009647L_c	0.43	0.3075	0.346
Shrinkage along Y (%)	0.880784	0.58	0.4533	0.4634
Shrinkage along Z (%)	3.361	3.5	3.3401	3.34877

Table 2 shows a comparison of optimum value of Shrinkage Model, Machine Manufacturer Suggested and Pattern search Tool and Genetic Algorithm in MATLAB 2011, and shrinkage % for each of the experiment in X, Y, Z direction by empirical model equation by using pattern search tool and Genetic Algorithm.

V. Conclusion

The following conclusions can be interpreted regarding the results obtained by applying the Pattern Search Tool and Genetic Algorithm available with the optimization tool box of MATLAB 2011. For the Empirical model equation the optimum Shrinkage (%) values obtain in X- direction 0.3075 By pattern search tool. For the Empirical model equation the optimum Shrinkage (%) values obtain in X- direction 0.346 By Genetic Algorithm. For the Empirical model equation the optimum Shrinkage (%) values obtain in Y- direction 0.4533 By pattern search tool. For the Empirical model equation the optimum Shrinkage (%) values obtain in Y- direction 0.4634 By Genetic Algorithm. For the Empirical model equation the optimum Shrinkage (%) values obtain in Z- direction 3.3401 By pattern search tool. For the Empirical model equation the optimum Shrinkage (%) values obtain in Z- direction 3.34877 By Genetic Algorithm.

It can be concluded that the Pattern Search Tool and the Genetic Algorithm gives almost the same value for the optimum value of shrinkage (%) and its dependent parameters i.e. Laser Power (Lp), Scan Length (Lc), Beam Speed (Bs), Hatch speed (Hs), Part Bed temperature (Tb), but pattern Search Tool method can be considered as the best tool for optimizing the model equation as it is simple to use and no manipulations in the software parameters are required.

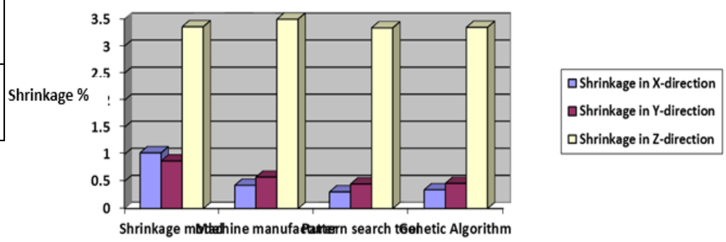

Figure 2 Graphical relations.

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