# Parametric Analysis for Selective Laser Sintering of a Sample Polymer System

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## Abstract

An experimental cross parametric relation evaluation and a parametric analysis effort were conducted to assess the effects of the major Selective Laser Sintering (SLS) process parameters on the quality of the SLS products using a sample powder system. The sintering results are discussed in terms of the major input parameters including laser power intensity, beam profile, scanning speed, and scanning path as well as powder packing density. The results indicate that increasing powder packing density is the most beneficial way to improve the SLS product quality.

## 1. Introduction

In a SLS process, a computer-controlled laser beam is used to heat the powder bed to cause localized sintering [1,2]. It is a complex process which involves many process parameters. The laser beam properties, such as laser beam profile, intensity, and wavelength, as well as its scanning speed and scanning path are very important parameters. In fact, these parameters together with powder material properties and sintering environment are key factors in a SLS process. An understanding of these parameters is very important to the successful SLS process control. Therefore, a cross parametric evaluation and a parametric analysis effort were conducted to assess the effects of the major process parameters, including laser power, beam scanning speed and powder packing densities, on the quality of the SLS products using a sample powder system in a single scan and single layer basis. The primary objective of this research is to determine the most effective factors for SLS part production qualitatively. It is focused on the investigation of the effect of the processing parameters on the sintering geometry definition, sintering depth, and sintering density. For simplification, the effects of environmental influences and materials were fixed. Machinery influences were neglected other than the powder packing density.

## 2. Experimental Approaches

### 2.1 Material Selection

Many powder materials can be used as the starting material for the SLS process. The sintering material for a SLS process is chosen by considering its sintering capability, mechanical property after sintered, and radiation stability of the material. Additionally, the melting point of the material need to be considered for a given laser power. Polycarbonate powder was selected as a sample material for this experiment. It possesses good mechanical properties, good sintering capability and high radiation stability in polymers. The IR spectrum of polycarbonate indicates that the highest absorption rate is in the range of wavelength from 5.0μm to 11.0μm.

### 2.2 Laser Selection

The choice of the laser is solely dependent on the selection of the powder material, its optical properties, thermal properties and the availability. Since polycarbonate powder had been chosen for this experiment, the $CO_2$ laser became a proper choice. Its wavelength is about 10.6μm which is in the best absorption rate range of polycarbonate.

The experimental $CO_2$ Laser has a frequency range of 50-400 Hz, TEMoo 95% purity of mode quality, and ± 5% of power stability (30sec. warm up time), and 3mm of output beam size. Laser beam profile was measured at surface of powder bed by using profilometer. Gaussian beam profile was observed with a beam waist of about 1.4 mm in 100% duty cycle. It was also noticed that a smooth Gaussian profile of the laser beam can be obtained only at the full duty cycle [3].

### 2.3 Experimental facilities

The experimental SLS machine, Bambi [4], was used in this experiment. A laser beam profilometer was used to measure the beam profile. JSM-35 Scanning Electron Microscope (SEM) was utilized to observe the sectional sintering geometry and analyze the changes of sintered microstructure. SEM has a much larger depth of field than the optical microscope and is useful for the observation of an uneven surface.

### 2.4 Sample preparation and measurement

Cross section of the sample was taken from the sintered layer as shown in Fig. 1. Sintering depth can be identified from a so-called sectional sintering geometry. Sectional sintering geometry is a section view of the sintered part (path). It is defined from sintered surface, along the direction of laser beam (Z-axis), to a region that sintering density appears obviously reduced(Fig.2). The sintering depth is defined within a solid sintering region. It is evaluated by means of the mean heights of the solid sectional sintered portions. The sectional sintering geometry can be clearly observed and measured using SEM.

The fractional density is defined as the area ratio of the solid sintered region to the void region within the average height of the sintering geometry.

## 3. Experimental Results and Parametric Analysis

### 3.1 Sectional sintering depth vs. laser power and scanning speed

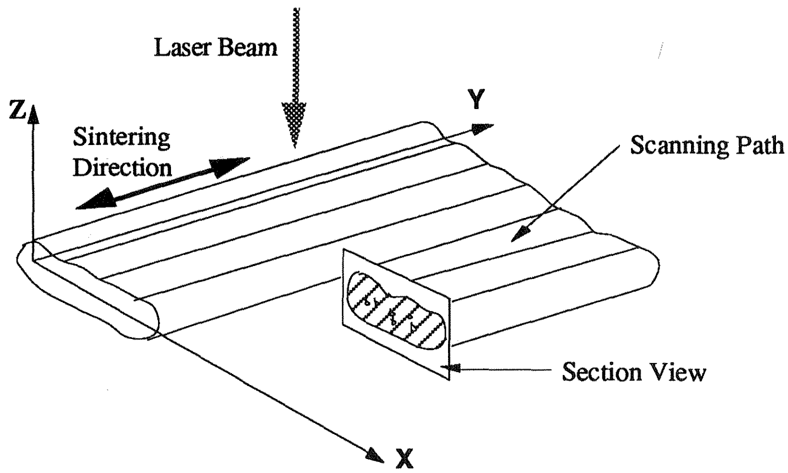


Fig. 1 Sample collection

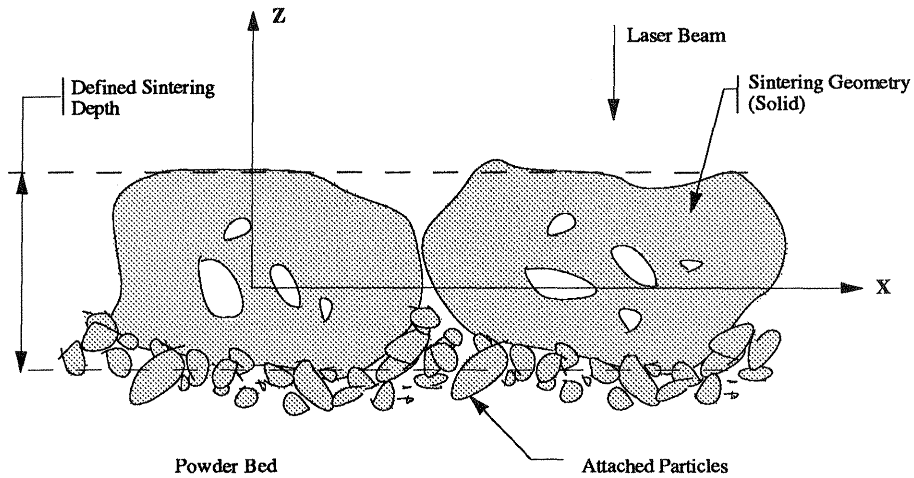


Fig.2 Determination of the sintering depth

Fig. 3 shows the relation of the sintering depth with scanning speed at different laser power 14, 16, and 20 W for single scans. The results can be explained using the SEM micrographs of the sintered lines. For example, for the laser power of 20 W, laser ablation occurred in the low scanning speed range up to 4 in/sec (Fig. 4a), resulting in a material removal during sintering and thus a thinner sintering depth. As the scanning speed increases, more and more sintering is involved in the process (Fig. 4b), the sintering depth first increases to a point where 100% sintering (no material removed) occurred and then decreases due to the shorter interaction time. Similar results were observed in the SLS of single layers [3].

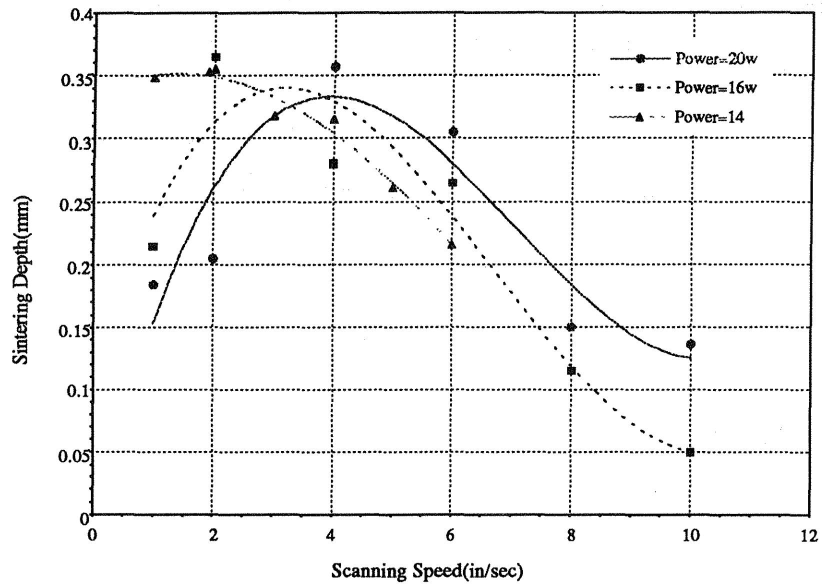


Fig. 3 Sintering depth as the function of scanning speed and laser power

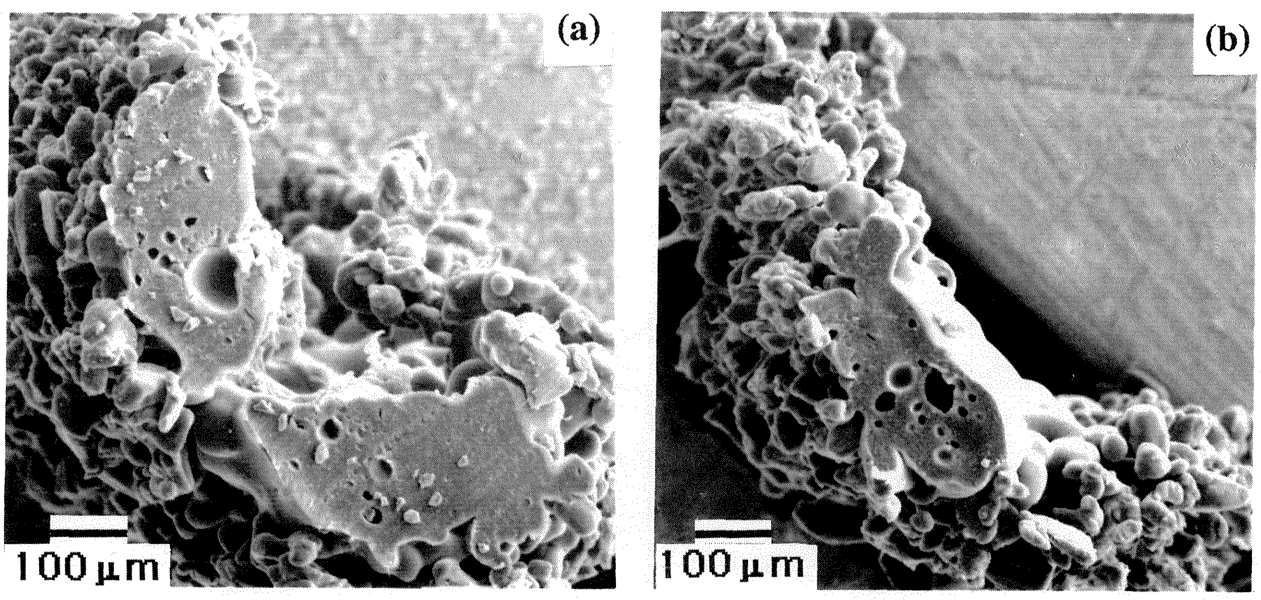


Fig. 4 A section view of sintered part at (a) P=20w, v=2in/sec, (b) P=20w, v=8in/sec.

3.2 Sectional sintering geometry versus powder packing density

Fig. 5 and Fig. 6 show the relations of the sintering depth and width with the powder packing density respectively. Two different packing densities (36.4% and 80% ) result in totally different sintering geometry. High powder packing density results in a larger sintering width and a

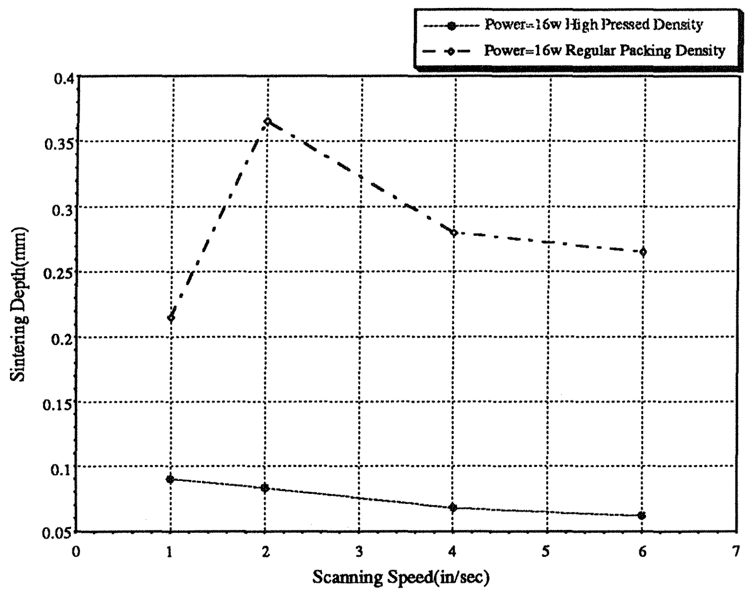


Fig. 5 The effect of packing densities on the sintering depth

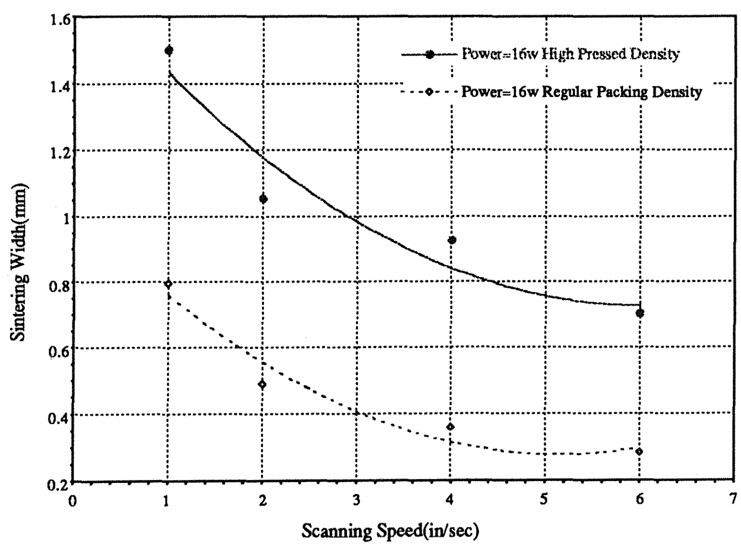


Fig. 6 The effect of the packing density on the sintering width in a single scan

smaller sintering depth. The higher of the powder packing density, the higher thermal conductivity that makes heat flux conduct fast, and therefore the wider sectional sintering geometry. Meanwhile, it reduces the laser lights passing through the powder bed so that the sintering depth is greatly decreased. It is notable that ablation was mild in the high range of powder packing densities due to the combination effect of relatively high thermal conductivity and high reflectivity of the pressed surface. Local curling and shrinking can be also reduced by increasing packing density of powder.

The significant effect of the packing density on the SLS product quality is shown in Fig. 7. In this figure, two samples were sintered under same sintering conditions other than the packing densities which were 0.43 g/cm$^3$(left) and 0.82 g/cm$^3$(right). It is obvious that the sample with higher packing density has a very smooth surface finish, clean edge definition, higher sintered density, precise geometric shape and less shrinkage than the lower one.

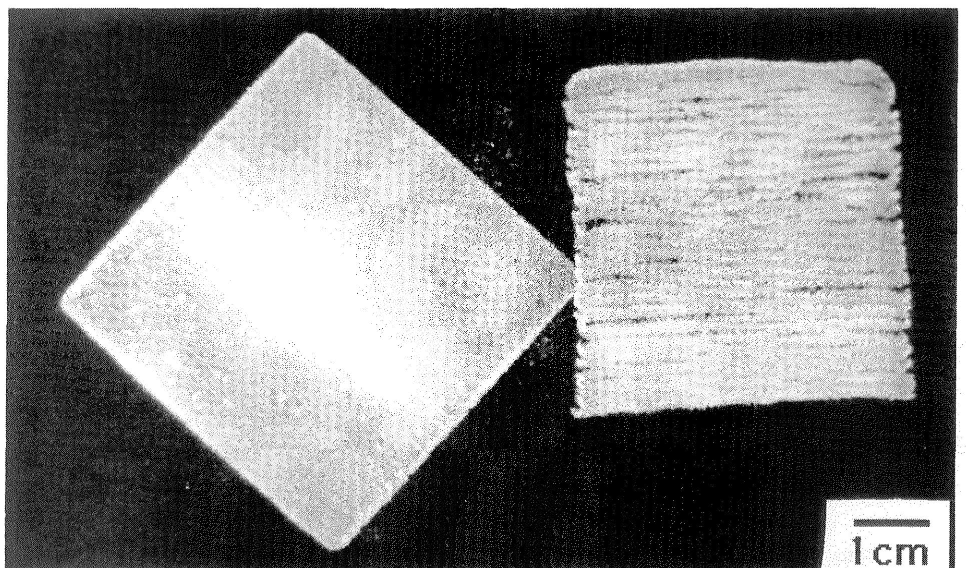


Fig. 7 A photograph showing the surface finish and shape generation of the different packing densities

3.3 Sectional sintering geometry versus beam profile and beam overlapping

Sectional sintering geometry can be changed when the scanning spacing or the amount of overlapping changes. The effects of the beam scanning path overlapping with the sintering depth are plotted in Fig. 8 which indicates that the sintering depth can be increased up to 70%. The fractional density also has significant changes (Fig. 9). The fractional density can be enhanced to a full density in the single layer basis.

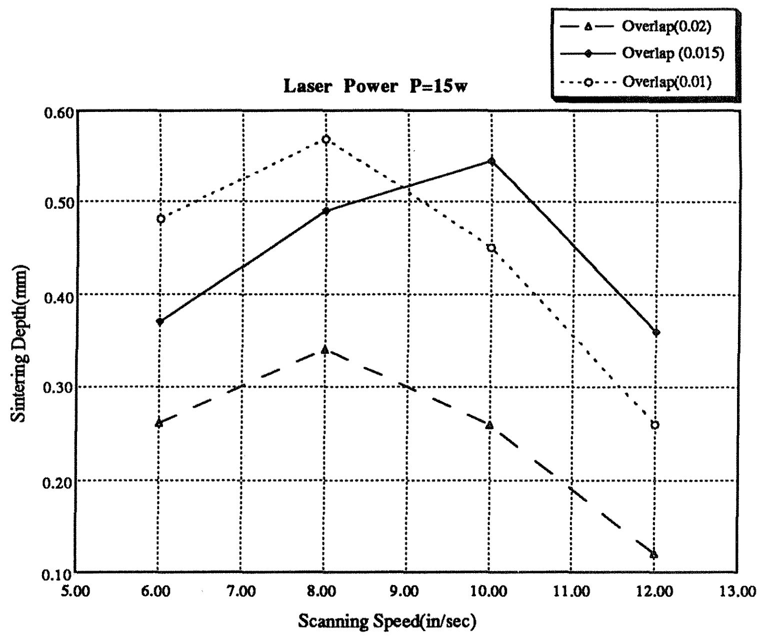


Fig. 8 Sintering depth corresponding to beam scanning path overlapping(in)

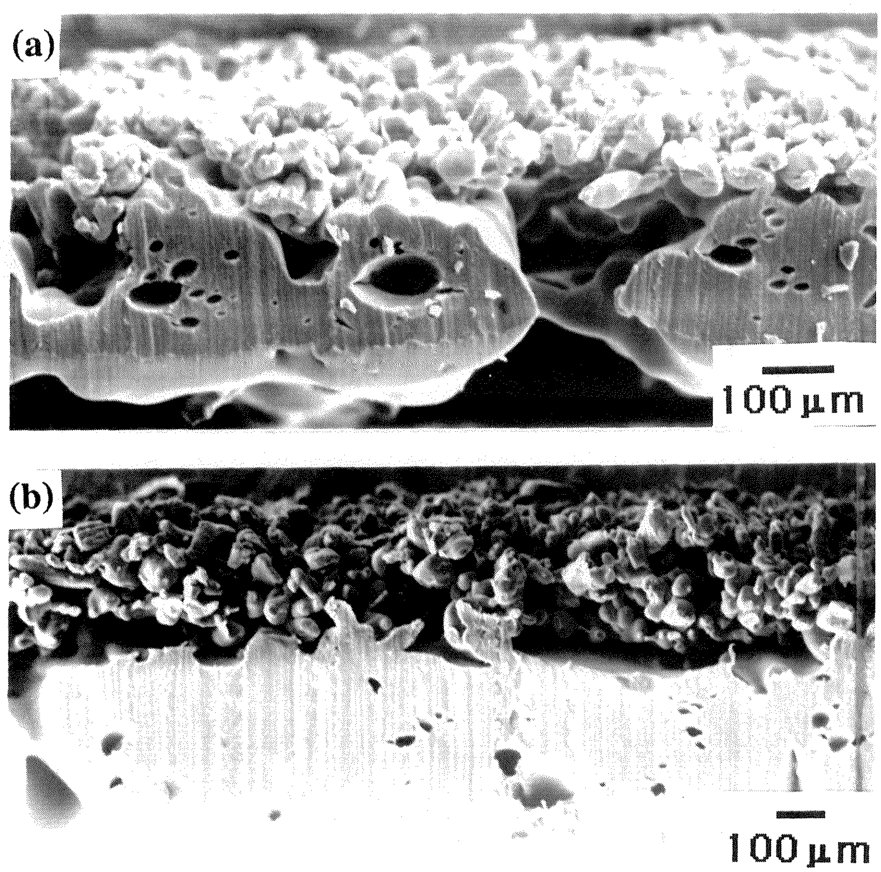


Fig. 9 Sintered samples with laser beam scanning path overlapping (a) 0.5mm, (b) 0.25mm.

## 5. Summary and Conclusions

Selective Laser Sintering involves many process parameters. It is not at all obvious how to set these parameters to obtain an acceptable part from a particular powder. Suitable parameters are material-dependent and part shape-dependent. A 'smart process' is a long term objective of SLS research. The focus of this research is on how the dominant parameters or factors affect the SLS process on the single scan and single layer basis. These parameters include laser power, laser beam scanning speed, scanning overlapping, and powder powder packing density.

This fundamental research has provided a qualitative parametric analysis for the SLS process. It was found that higher beam scanning speed produces a flat sectional sintering geometry. In other words, increasing laser duration time contributes to a larger value of sintering depth and vice versa. The higher laser powers and lower scanning speeds, the larger values of the sintering depth and sintering width. This is not always favorable, because ablation occurs once the input laser energy exceed certain levels. There is a limitation to the maximum sintering depth attainable. Increasing the powder packing powder density results in very significant sintering geometry changes. The main effects include increasing sintering density, preventing the local curling and balling, dramatically improving the sintering surface finish and edge definition, and reducing sintering shrinkage. Laser beam scanning path overlapping can increase the sintering depth and the sintering density.

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