MEASURED ENERGY DENSITIES FOR POLYAMIDE 12 AND COMPARISON OF VALUES CALCULATED FOR LASER SINTERING.

Antoine Chalancon[1] and David Bourell[2]

[1]National Engineering School of Saint-Etienne, [2]Laboratory for Freeform Fabrication, Mechanical Engineering Department, the University of Texas at Austin

Abstract

Energy density is a key factor in the Laser Sintering (LS) process, and impacts the properties of the built parts. Processing parameters have an important effect on Laser Sintering. This paper focuses on the evaluation of various energy density equations. Experiments were carried out by varying processing parameters, namely, laser power, scan speed, hatch distance/scan spacing and layer thickness to change actual and calculated energy density. Relative density was estimated using the Archimedes method and mensuration. As a result, a correlation between the laser energy density and the relative density has been established. Finally, the effect of parameters is discussed.

Introduction

SLS is additive manufacturing technique that uses a laser as a power source to powder material. The specially of SLS process has been identified as one of the most promising area for production of engineering components. The absence of molds allows to produce intricate geometries and eliminates the post-processing steps thereby resulting in the shortening of the production cycle as well as the reduction of production costs.

Energy density is a key factor in the Laser Sintering process, and it impacts the properties of the built parts. The project was to measure energy density for polyamide 12 and compare values calculated for laser sintering and analyze them.

The usual equation of the laser energy density is [1] :

$$E_D = \frac{P}{SS \times H \times t} \tag{1}$$

Where,
E_D : Energy Density [J/mm^3]
P : Laser Power [W]
SS : Scan Speed [mm/s]
H : Hatch Distance [mm]
t : Layer Thickness [mm]

Another equation exists, named the Andrew number [1-2] :

$$A_N = \frac{P}{SS \times H} \quad (2)$$

Where,
A_N : Andrew Number [J/mm²]

This last equation does not use the layer thickness. The work was to understand the effect of this parameter t and its importance in (1).

The energy density equations (1) come from the power formula :

$$E = P \times t$$

Knowing that :

$$t = \frac{D}{SS}$$

finally

$$E = \frac{P \times D}{SS}$$

For the area energy E_s :

$$E_s = \frac{E}{A_L} = \frac{4 \times P \times D}{SS \times \pi \times D^2} = \frac{4 \times P}{SS \times \pi \times D}$$

$$E_S \approx \frac{P}{SS \times D}$$

For the volume energy E_V:

$$E_V = \frac{E}{V} = \frac{4 \times P \times D}{SS \times \pi \times D^2 \times t} = \frac{4 \times P}{SS \times \pi \times D \times t}$$

$$E_V \approx \frac{P}{SS \times D \times t}$$

The above equations are for a single scanned track, the energy density. For a two dimensional shape, D is replaced by hatch distance

Experimental procedure

By trial and error, the parameters values of building of the parts have been tuned. The energy density has been calculated by the two equations (1) and (2), with and without the layer thickness. Then, the relative density was measured and compared to the energy density.

The parameters are chosen according to the SLS machine limits in the laboratory:

t	P	H	SS
(mil)	(W)	(mm)	(inch/s)
3	15	0.01	400
3	25	0.01	400
3	35	0.01	400
3	45	0.01	400
3	55	0.01	400
3	24	0.004	400
3	24	0.006	400
3	24	0.008	400
3	24	0.01	400
3	24	0.012	400

The experiments are devised in two series :

1. The layer thickness, the hatch distance and the scan speed are set, and the laser power is increased for each new sample from 15 W to 55 W in 5 W steps. Above 55 W, the powder melts beyond the desired specifications, and below 15 W, the laser is not powerful enough to melt the powder.
2. The hatch distance varied while keeping the others parameters constant. The range of the hatch distance is split into 5 values too.

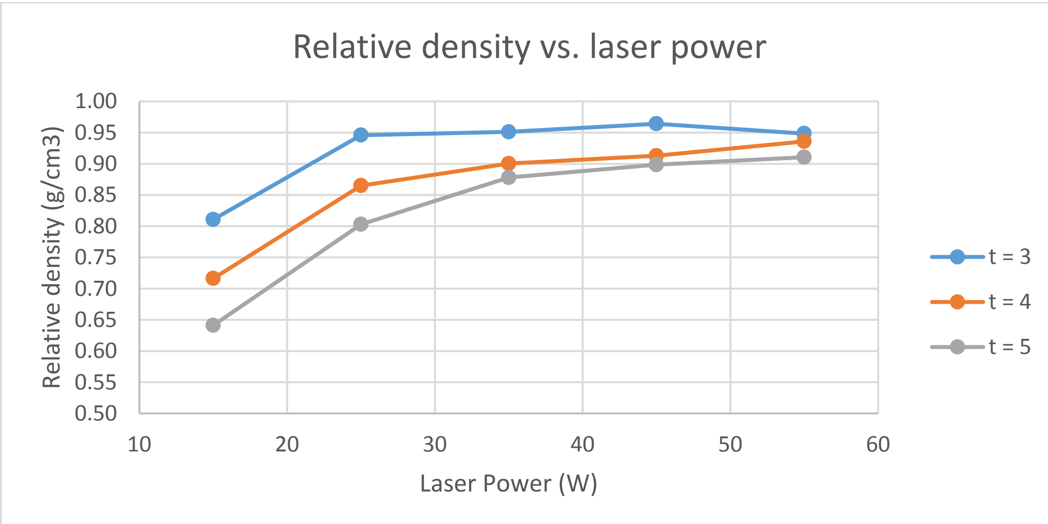
Three series exist with layer thickness equal to 3mil, 4mil and 5mil.

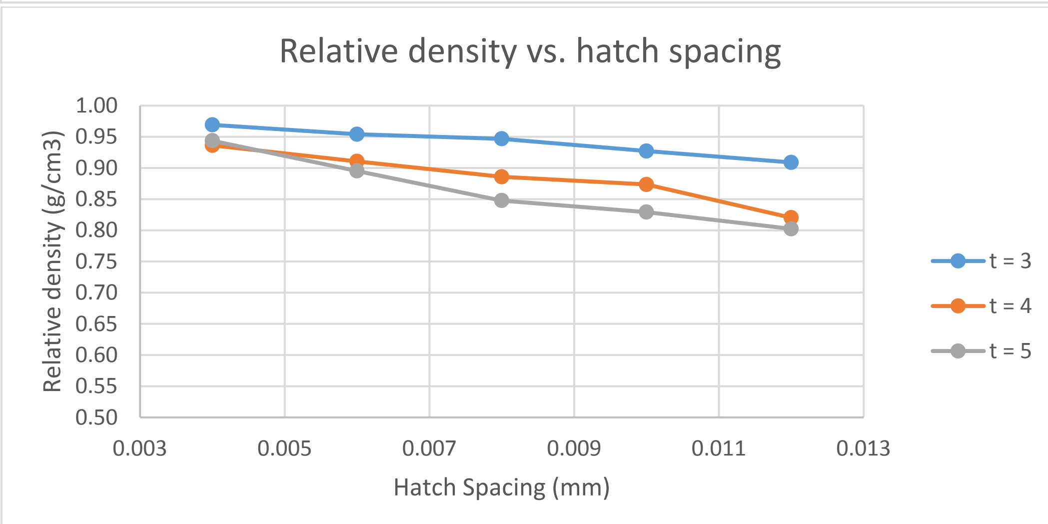
The samples are small cubes approximately 0.345 inch.

Results and discussion

In total, thirty cubes were made. By the mensuration method, the cubes lengths and weight have been measured. After obtaining the volume, the density equation is obtained by $\rho = \frac{m}{v}$.

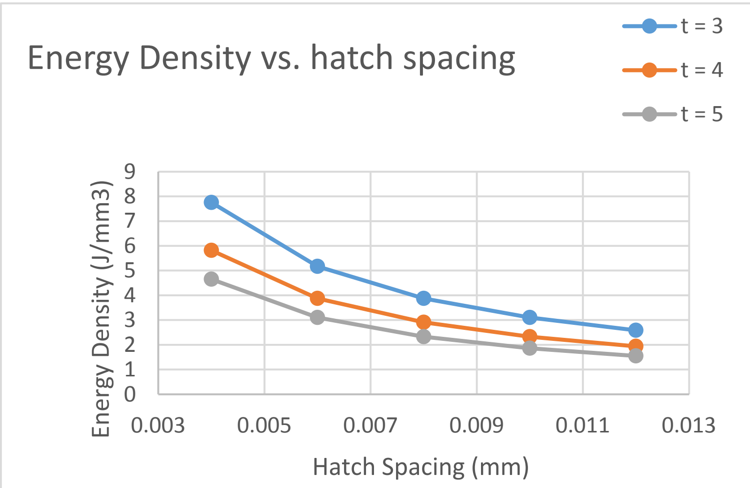
The first curves obtained are the sample relative density depending on the laser power and the relative density depending on the hatch spacing.

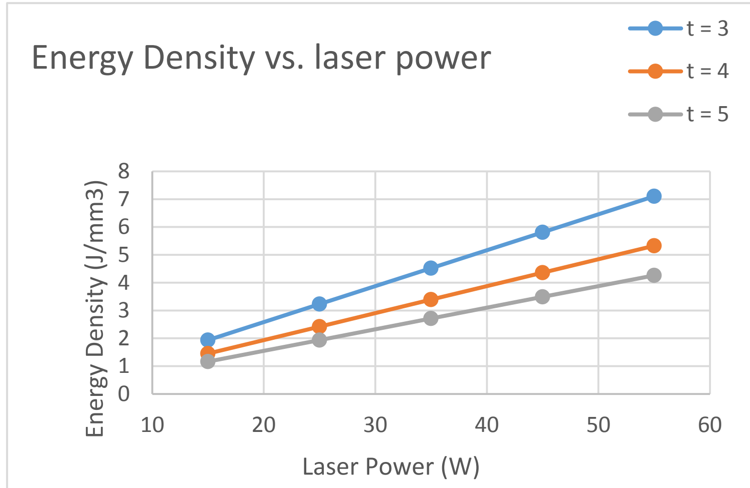


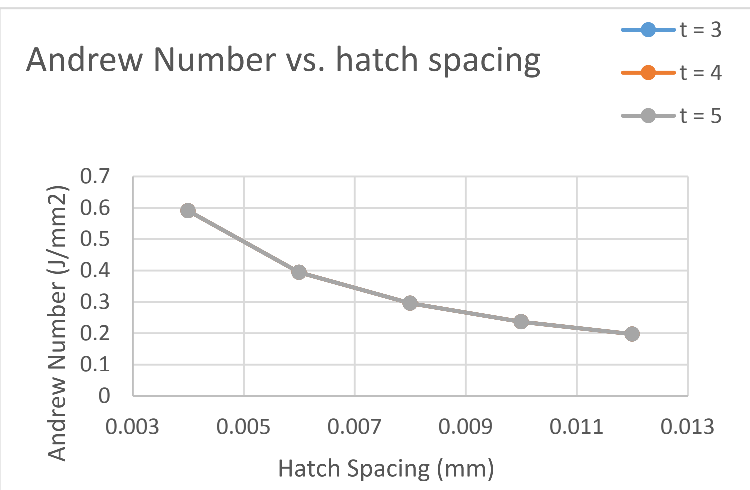


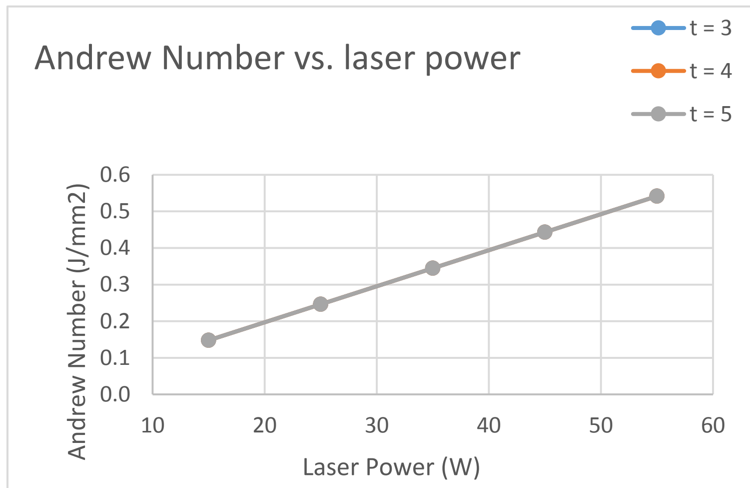
Regarding the relative density dependence of the laser power, from one point, the curves do not increase. At the beginning, the laser is too weak to melt the powder correctly. Then, the relative density of the part stabilizes. Furthermore, we noticed, the layer thickness is important for the relative density. It is normal because a part with layer thickness densest is more heavy than a part with layer thickness the less dense.
For the relative density dependence of hatch spacing, the decrease is to be expected. When the hatch spacing increases, the relative density decreases because the part receives less energy per unit area of surface.

It is seen that the space between the different curves is low after the laser power equals to 40 W for the layer thickness 4 and 5 mil. And the space between the different curves is small before the hatch spacing 0.008mm.





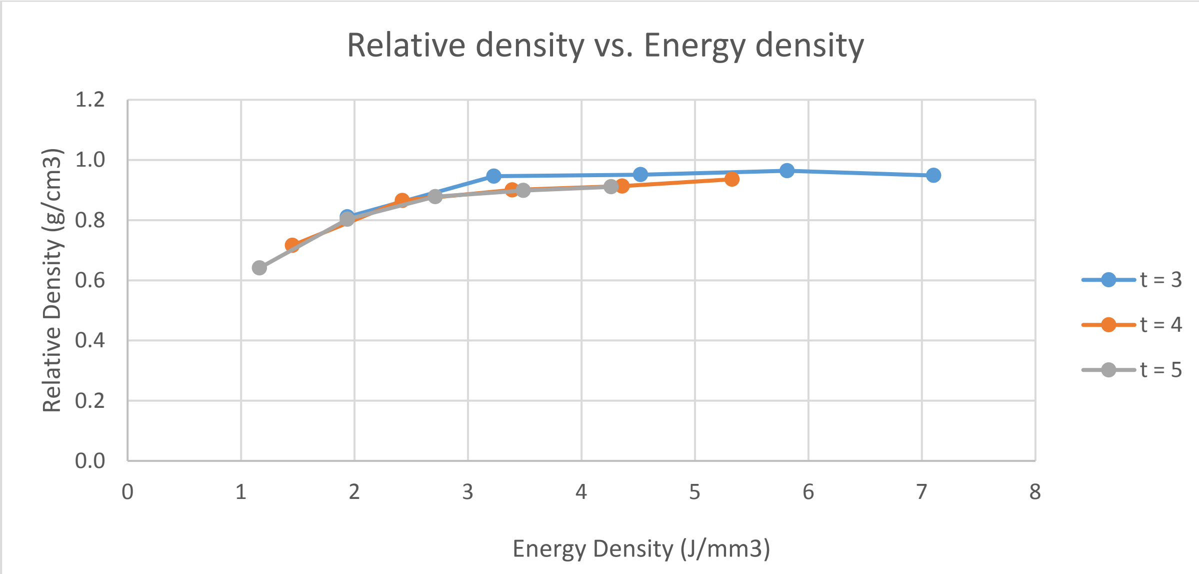


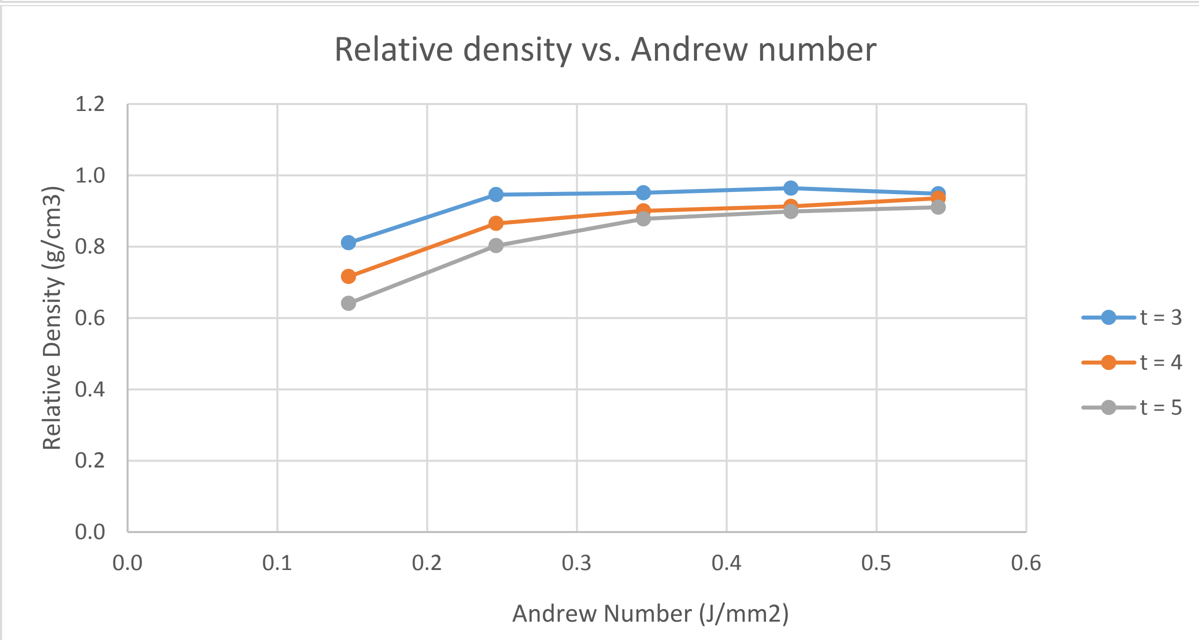


These charts show the importance of the parameters in the energy density equation and Andrew Number.

Concerning the laser power, the increase of the power sets the energy density up. The layer thickness plays the role of the slope or the straight line. For the hatch spacing, with the increase, the energy density decreases. Moreover, with the rise, the curves of t = 3, t = 4 and t = 5 mil move closer.

Regarding the Andrew number, the curves look like the energy density curves. However, there is not much difference between the different layers thickness. It is logical, this parameter does not apply in the equation.





Finally, the plots of the relative density depending on the energy density and Andrew number can be built. The curves seem the same in the two charts. For the equation with the layer thickness, this parameter looks to move the curves in the axis x. In the Andrew number, depending on the layer thickness, the curves are more or less high in the ordinate relative density. Moreover, the curves meet in the end of the chart for the Andrew number.

Conclusions

The aim of the project was to measure energy densities for polyamide 12 and compare the values calculated for the laser sintering. The design of experiments allows to build a smart experiment.

The plots obtained allow to observe the parametric influence. The relative density is a great reference to notice the changing of energy density due to the adjustments. As expected, the layer thickness plays a crucial part about the relative density. Nevertheless, we noticed that the curves depending on the layer thickness join themselves at some points. We can conclude from a certain point, 40 W in the polyamide 12 case, regarding the laser power. This parameter is more important than layer thickness. Moreover, usually the laser power is near 40 W in the laboratory of freeform at Austin. That is why we have to configure, first, the laser power in my opinion; in the same way for the hatch spacing. Under a point, 0.008 mm, the curves are very close. And it is under this point, the SLS machine normally works in order to build good parts.

Concerning the charts with the relative density depending to Andrew number, I can conclude the layer thickness has little impact. In the graph with the energy density number, the layer thickness homogenizes the curves depending the layer thickness, in this way to cancel the difference due to this parameter.

References

1. Shane Collins. Standard Guide for Determining Global Energy Density of Metal Laser Sintering Systems. In order to compare metal laser sintering systems and materials a standardized method of determining the global energy density needs to be established. (6-10-2015).

2. James Christian Nelson. Selective laser sintering : a definition of the process and an empirical sintering model. Thesis of doctor. The university of Texas at Austin. (May 1993).

3. Hengfeng Gu, Haijun Gong, Deepankar Pal, Khalid Rafi, Thomas Starr, Brent. Influences of energy density on porosity and microstructure of selective laser melted 17-4PH stainless steel. Solid Freeform Fabrication (2013).

4. C.W. Ku, I. Gibson, W.L. Cheung. Selective laser sintered CastForm™ polystyrene with controlled porosity and its infiltration characteristics by Red Wax. Solid Freeform Fabrication (2002).

5. John Williams, David Miller and Carl Deckard. Selective Laser Sintering Part Strength as a Function of Andrew Number, Scan Rate and Spot Size. Solid Freeform Fabrication (1996).