EFFECTS OF LASER WINDOW DEGREDATION ON LASER POWER AND DISTRIBUTION IN LASER SINTERING

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Abstract

Laser power is a key parameter in the laser sintering (LS) process, and tight control on laser power is necessary to produce quality parts with desirable mechanical properties. Unfortunately, temperature limitations hinder real-time monitoring and feedback of laser power within the process chamber. Therefore, in order to maintain consistent laser power during an LS build, the laser window, which provides a barrier between the processing chamber and the laser housing, must remain clean throughout the build. However, material outgassing leads to the buildup of condensation on the window, thereby reducing the amount of energy imparted to the powder bed. The buildup of condensation also necessitates frequent cleaning of the laser window and significantly reduces its life. Thus, laser window replacement is a large source of cost in a production environment. To compensate for the loss of laser power through the window, current practice is to steadily increase the laser power at the laser source during the build. This practice can be largely inaccurate, as it is difficult to predict the loss of laser power through the window at various stages in a given LS build. Thus, to achieve consistent mechanical properties in this manner, a trial and error-based approach is used. The study presented in this paper aims to characterize laser power and distribution for various levels of laser window degradation. In addition, methods to reduce or eliminate the buildup of condensation on the laser window are explored in an effort to improve the consistency of part quality, as well as to reduce maintenance requirements and costs.

1. Background

Mechanical properties of laser sintered (LS) parts are primarily determined by the amount of thermal energy they absorb during each layer of the laser sintering process. Poor thermal distribution across the part bed is perhaps the largest contributor to inconsistency in part quality in LS, and has been the focus of study in recent research [1,2]. The research presented in this paper focuses on the second largest contributor to inconsistent part quality: the decrease of laser power and widening of the beam as gasses condense on the laser window. The resultant residue creates a significant barrier between the laser and the LS processing chamber, hindering the laser beam from passing through. A schematic of a laser sintering machine can be seen in Figure 1, where the laser is shown passing through the laser window in route to tracing the cross-section of a part at the part-bed.

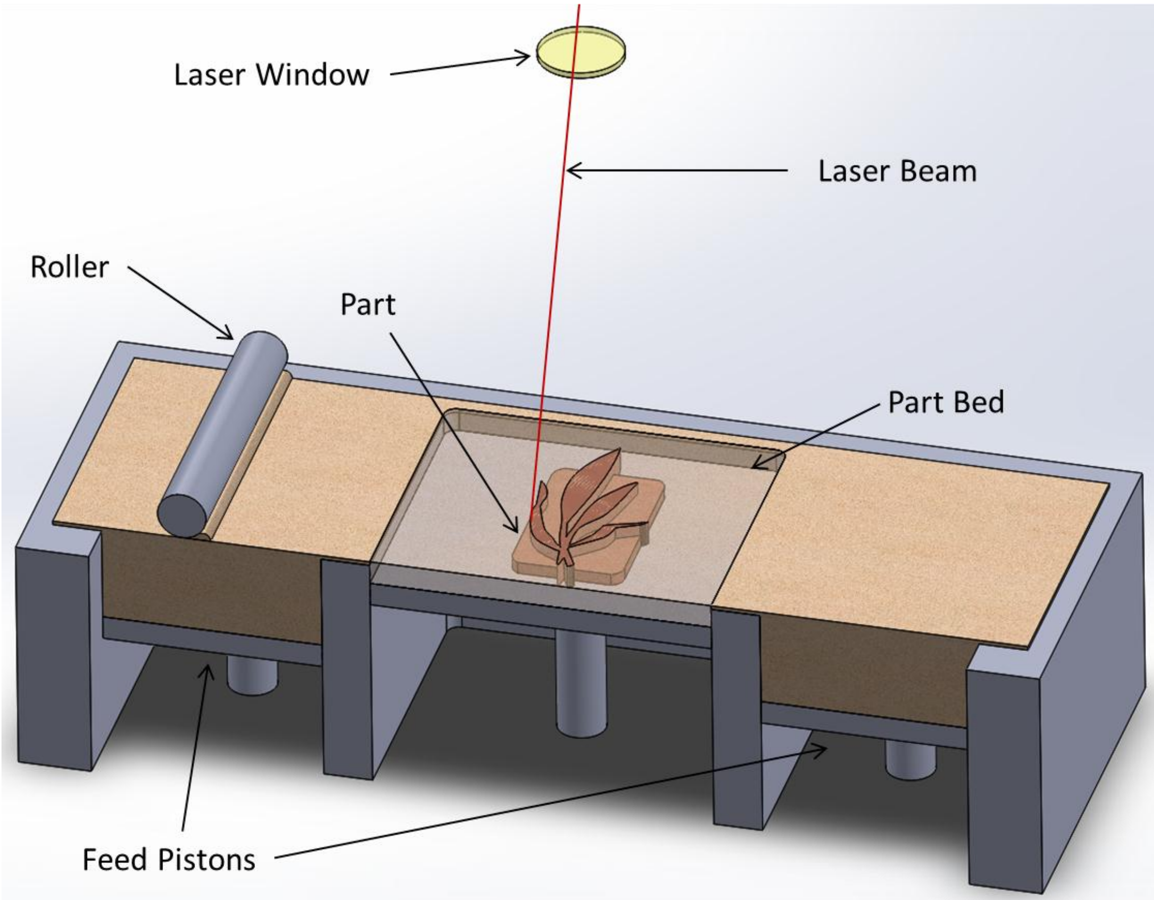


Figure 1. *LS machine schematic; laser window and beam*

In addition to the inconsistent part quality, the maintenance costs associated with cleaning and replacing laser windows are high. Traditionally, cleaning has been performed using alcohol and a soft cloth after each build. These repeated cleanings gradually scratch the surface of the window, eventually leading to its replacement. One laser window costs roughly $2,000, and each window has a lifespan of ~2-3 months when run on aerospace production machines at Harvest.

The gasses that condense on the laser window are released, or outgassed, from the plastic powder as heat is applied. In the cases of PA 11 and PA 12, the two most common laser sintering materials, at least one of these gasses is known to be water vapor. As seen in Figure 2, the post-condensation reaction between two PA 12 monomers involves the release of a water molecule. This reaction is activated by thermal energy and aided by the flow of Nitrogen through the LS processing chamber, which keeps the chamber dry. The chemical makeup of other gasses released by various LS powders is presently unknown to the authors, although it is suspected that volatile monomers, oligomers, and powder additives (such as flow agents and whiteners) may be outgassed [3].

$$H\text{-}[NH\text{-}(CH_2)_{11}\text{-}CO\text{-}]_x\text{-}OH \quad + \quad H\text{-}[NH\text{-}(CH_2)_{11}\text{-}CO\text{-}]_y\text{-}OH$$

$$\Big\downarrow \Delta T$$

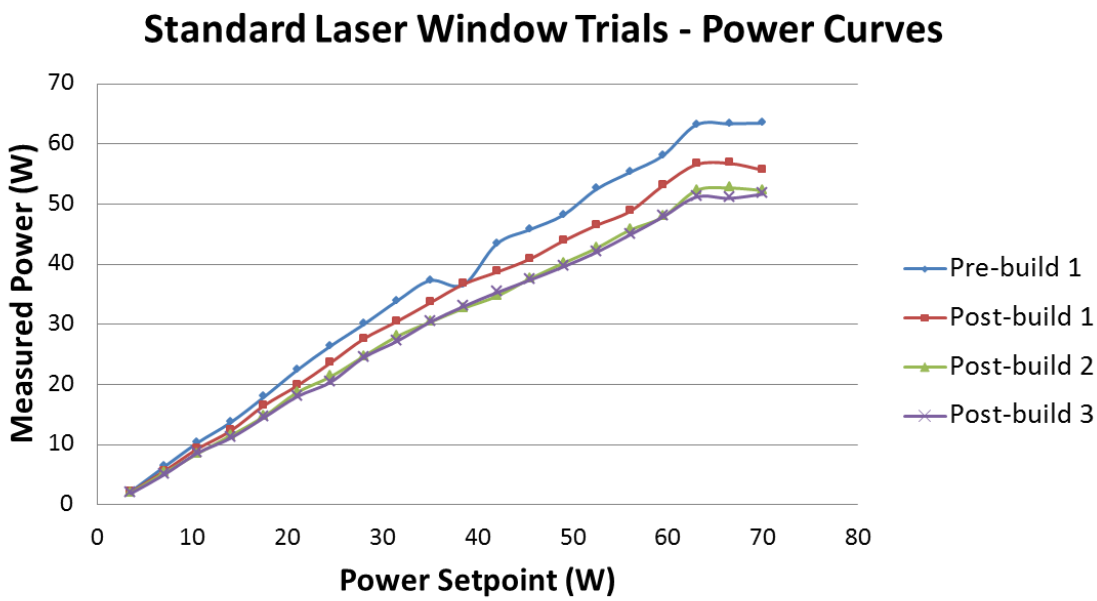
$$H\text{-}[NH\text{-}(CH_2)_{11}\text{-}CO\text{-}]_{(x+y)}\text{-}OH + H_2O \text{ (vapor)}$$

Figure 2. *Post-condensation reaction for PA 12*

3D Systems currently utilizes the flow of heated Nitrogen below the laser window to hinder the ability of gasses to condense on the window. A strip heater is used to heat the Nitrogen piping to 90 °C prior to entering the chamber. However, at a flowrate of 7.5 LPM, the Nitrogen itself heats up to a more mild temperature of roughly 50 °C. The incoming Nitrogen flows through three outlets directed diagonally upward at the lower surface of the window. The authors suspect that this flow of Nitrogen has limited effectiveness because it is relatively cool and may even force outgassed material into the window.

2. Effect of Residue on Laser Properties

In order to quantify the effects of window degradation on the properties of the laser at the part-bed surface, three test builds were run consecutively without cleaning of the window between builds. The builds were run at a laser power of 46 W using FR-106, a flame retardant, PA 11-based material from Advanced Laser Materials (ALM). The first two builds were geometrically identical, with a build height of 16” and a build time of 47 hours. The third build was 6” high and ran for 16 hours. Before and after each build, laser power was measured in 5% increments of the maximum available laser power, 70 W. Additionally, beam intensity profiles were measured for three cases: no laser window, a clean laser window, and the laser window at the end of the third build. The plots in Figure 3 show the nominal and normalized laser power curves measured at the end of each of the three builds, as well as the nominal and normalized power curves before the start of the first build. Residue buildup appears to cause a percentage drop in laser power, rather than a constant drop. This is readily seen in the normalized plot, where, for example, the post-build 1 laser power is roughly 10% lower than the pre-build 1 laser power for nearly all of the laser power set-points. For the third build, laser power did not drop significantly because the building time was low.



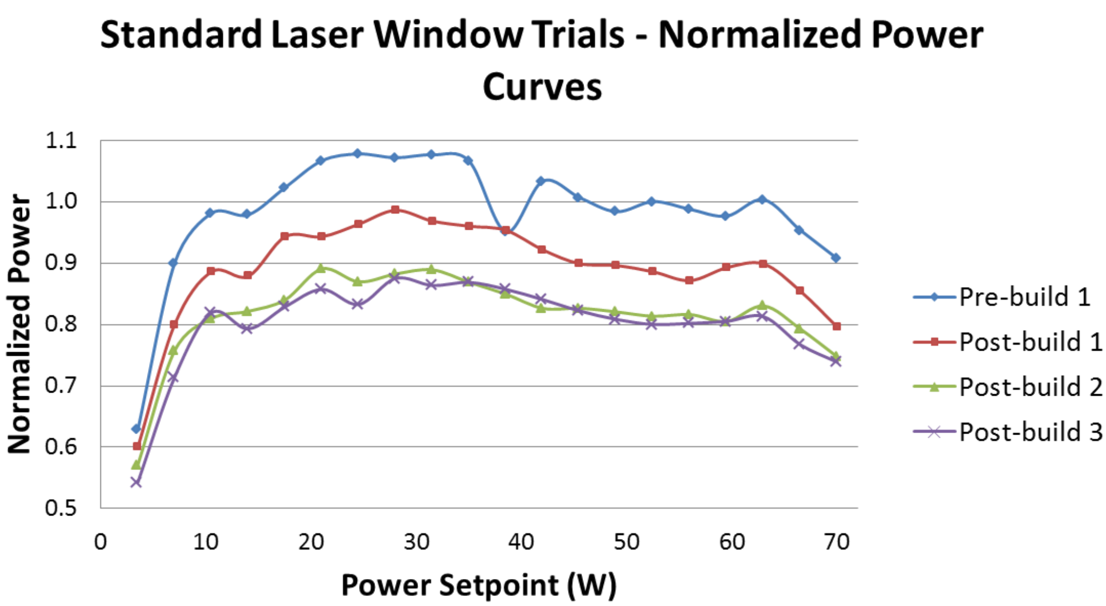


Figure 3. *Nominal and normalized power curves for the standard window housing design*

Residue buildup also affects the intensity profile of the beam. Table 1 summarizes the half-width values of the laser beam for the three previously mentioned cases. The values represent the averages of 250 measurements for each case. As shown Table 1, for lower laser powers such as 20 W, the intensity profile stays relatively unaffected by residue, but for higher laser powers such as 50 W, the intensity profile widens significantly with the presence of residue on the window.

Table 1. Half-Width Values for Various Beam Profiles

	20 W - No Window	20 W - Clean Window	20 W - Window After 3rd Build	50 W - No Window	50 W - Clean Window	50 W - Window After 3rd build
Half-Width in X-direction (µm)	511.3	471	520.2	568.4	553	734.9
Half-Width in Y-direction (µm)	506.1	477.9	510.2	530.1	550	718.6

Three-dimensional plots of the intensity profiles for the six cases can be seen in Figures 4 and 5. The three-dimensional plots are instantaneous images, and may not necessarily represent the average intensity profiles of the beam. For the higher wattage cases, the maximum power values appear to be clipped, which could cause errors in the half-width measurement. However, capturing the higher-power values would only serve to further decrease the half-width measurement for the clean and no-window cases, further separating them from the dirty-window case. The relative effect of residue buildup can still be visualized versus no window and a clean window for the 50 W case in Figure 5.

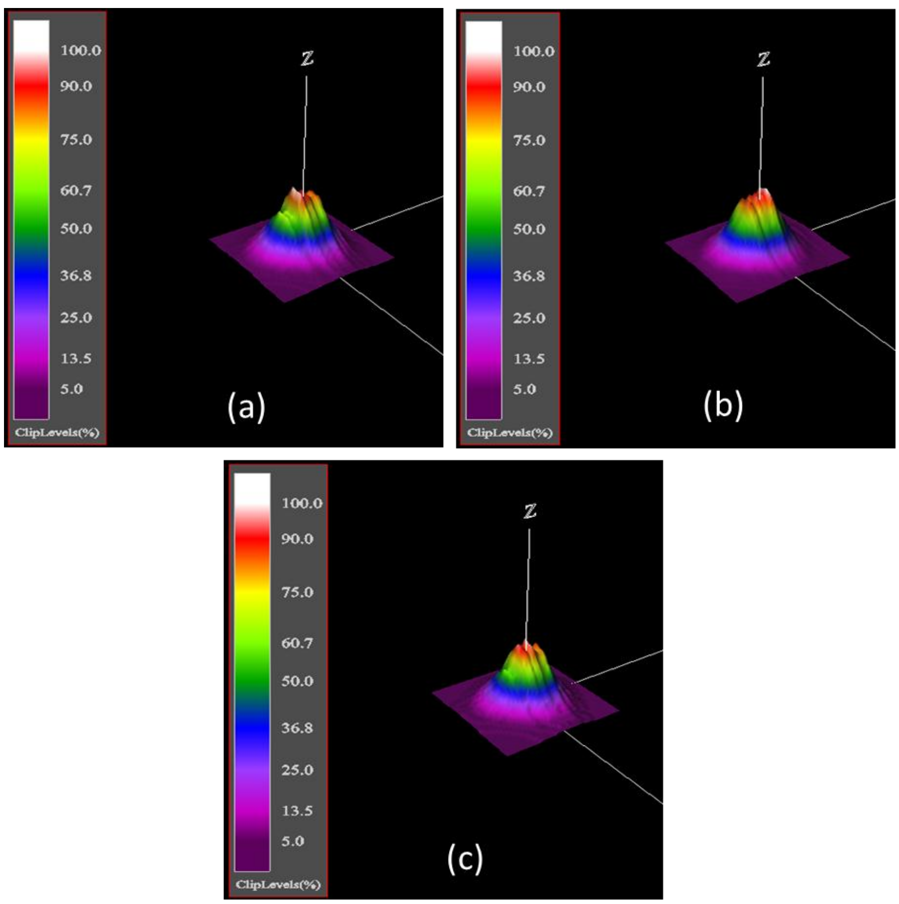


Figure 4. *(a) 20 W, no window (b) 20 W, clean window (c) 20 W, window after 3rd build*

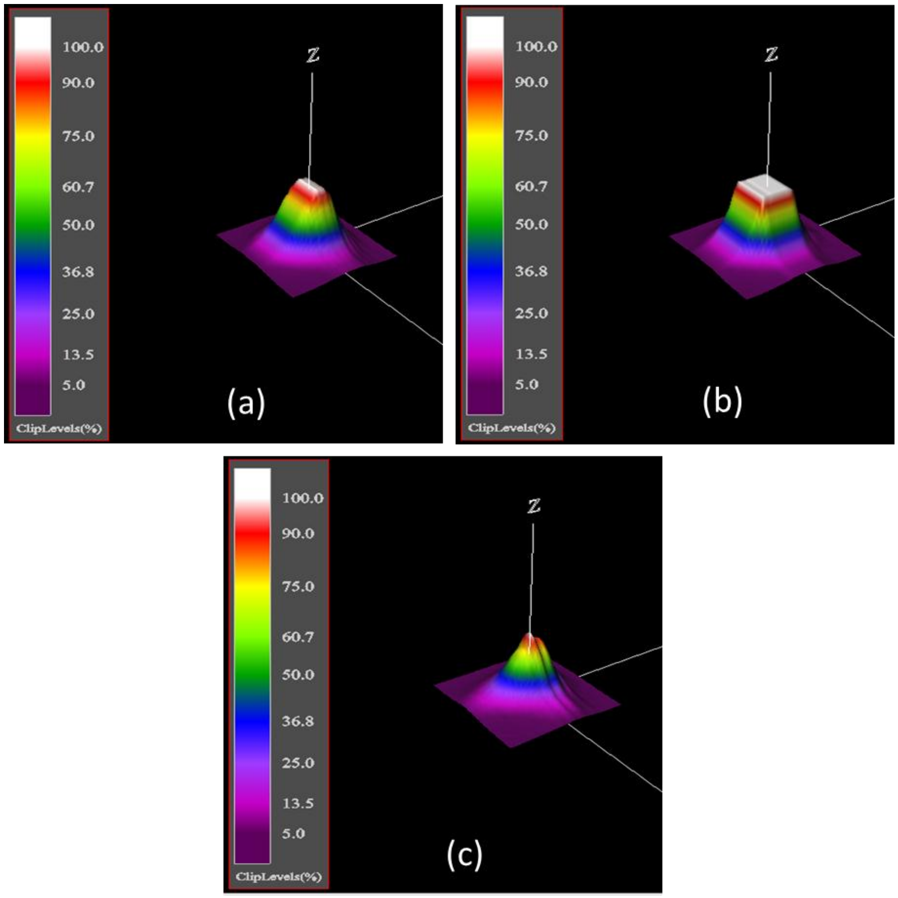


Figure 5. *(a) 50 W, no window (b) 50 W, clean window (c) 50 W, window after 3rd build*

3. Design to Reduce Buildup of Condensation

Due to the thermal nature of the residue issue, a thermal approach has been taken to prevent the condensation of outgassed material on the laser window. The concept behind the design is straightforward: heat the laser window to a high enough temperature so as to prohibit any outgassed material from condensing on it. Although the background information regarding the types of gasses in question is not fully understood, experimental methods can be used to determine what temperature is necessary to prevent condensation. Thus far, in the initial stages of research, a temperature of 125 °C has shown promising results.

Since the upper surface of the laser window is exposed to ambient conditions, providing adequate heat to the window could prove difficult using the standard housing. Thus, a modified housing was designed such that two laser windows are utilized with a small pocket of air in between. Two 50 W heaters are placed in between the windows along with a thermocouple to provide feedback. A PID temperature controller is used to hold the temperature at a set value. CAD images of the design can be seen in Figure 6, below.

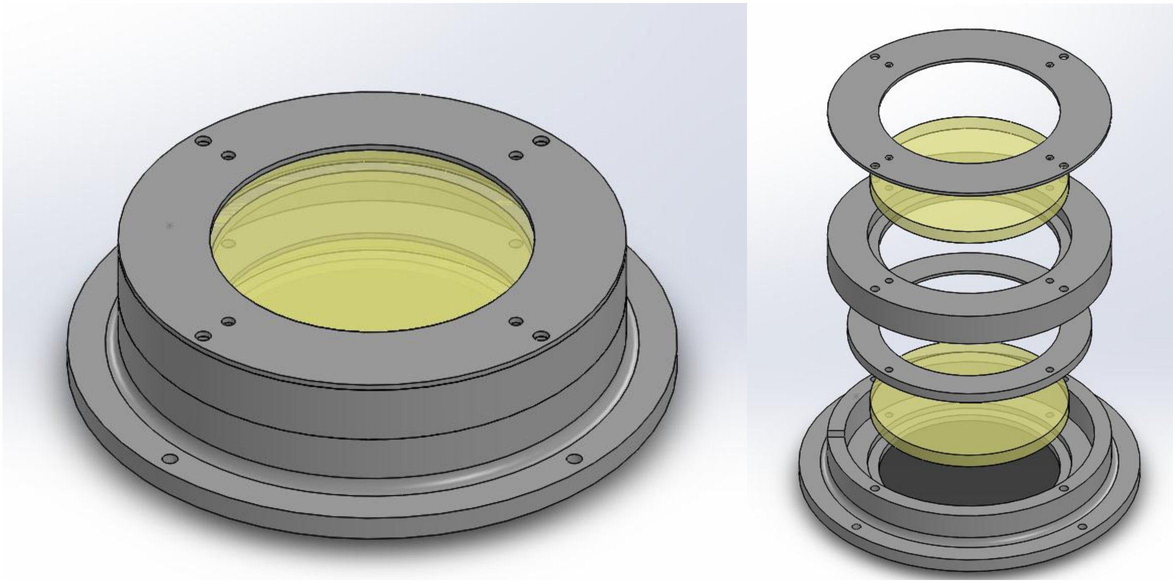


Figure 6. *CAD images of modified laser window housing*

4. Experimental Results

The first prototype was manufactured through laser sintering of glass-filled PA 12. This served as a form and fit prototype and provided an apparatus for testing thermal control. A 50 W heater was successful in heating air between the lenses to a temperature of at least 150 °C in an ambient environment; however, the prototype experienced melting, as seen in Figure 7, due to the high temperatures at the surface of the heater.

Figure 7. *First prototype of glass-filled PA 12 with melt-down*

A second prototype was machined out of Aluminum to be used in the LS machines. Due to the high thermal conductivity of Aluminum, a second 50 W heater was added to the second prototype to provide sufficient energy input, and insulation was added to the interior surfaces. Images of the Aluminum prototype with heaters and thermocouple can be seen in Figure 8. An image of the Aluminum mounted in a LS machine and undergoing heating can be seen in Figure 9.

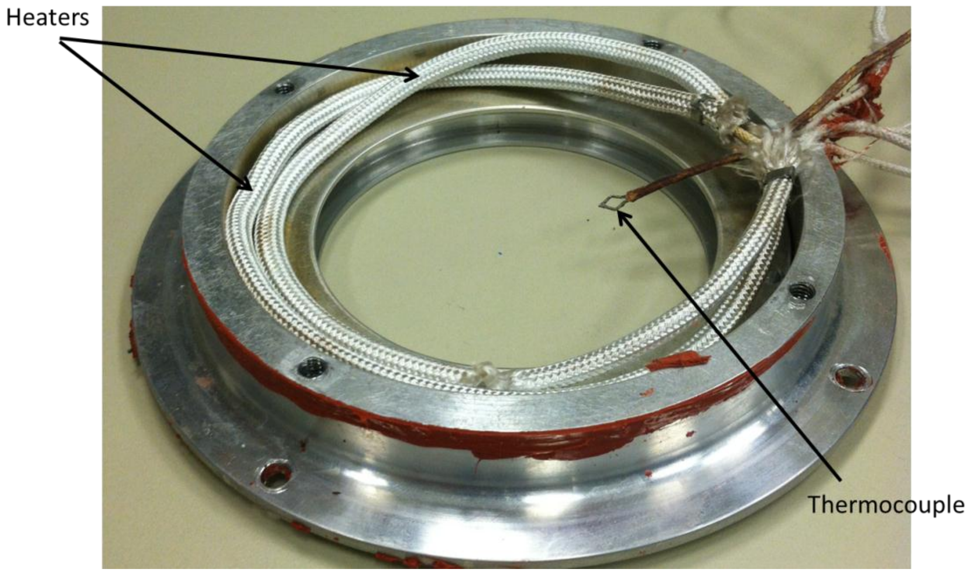


Figure 8. *Aluminum prototype with heaters and thermocouple*

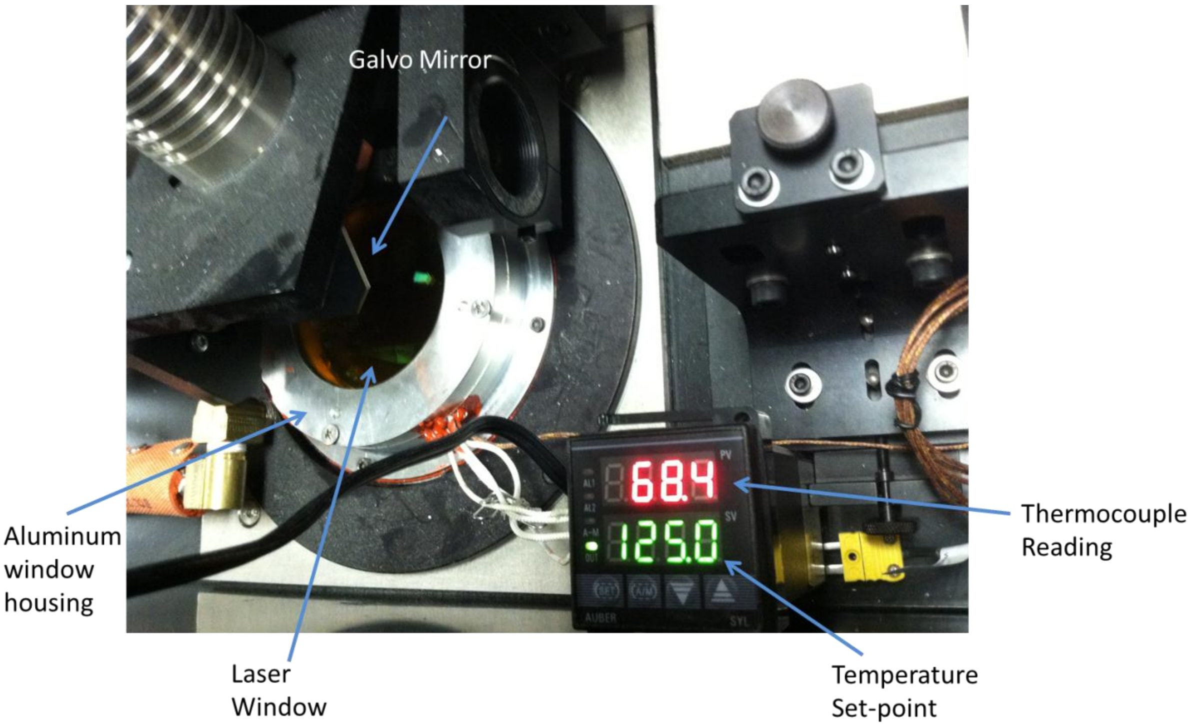
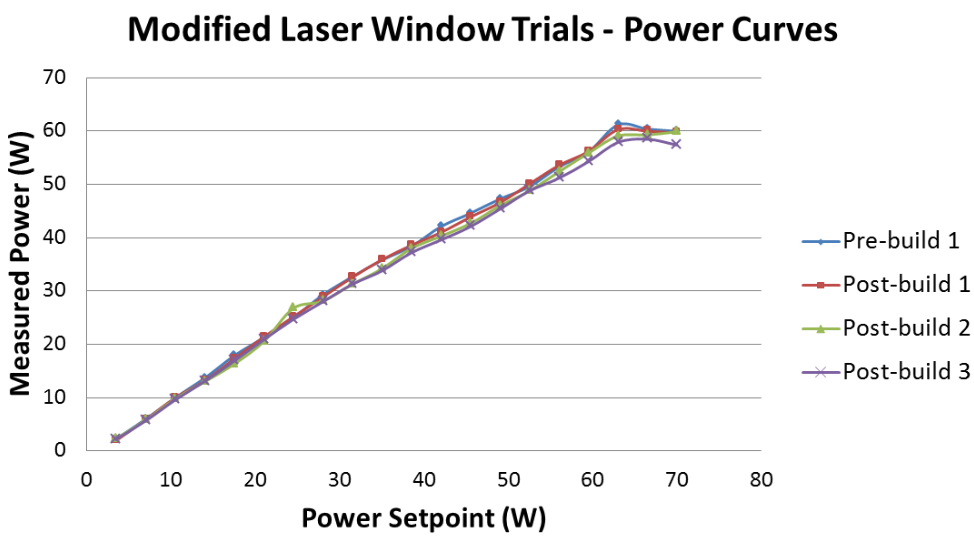


Figure 9. *Aluminum prototype mounted in LS machine and undergoing heating*

As in the testing of the standard window housing discussed in Section 2, three consecutive builds were run using the modified housing without cleaning the laser window in between builds. The builds run were geometrically identical to the builds discussed in Section 2 as well: the first two builds were 16” tall and lasted 47 hours, while the third build was 6” tall and lasted 6 hours. The air between the two laser windows was heated to a set-point of 125 °C and held throughout the course of each build. The 125 °C set-point was chosen to ensure that any outgassed water vapor would be unable to condense on the window during the build. Additional testing at higher temperatures will be the focus of further research, because it is unknown whether other outgassed materials have condensation points above or below this temperature. Laser power curves were recorded before and after build and can be seen in Figure 10, below.



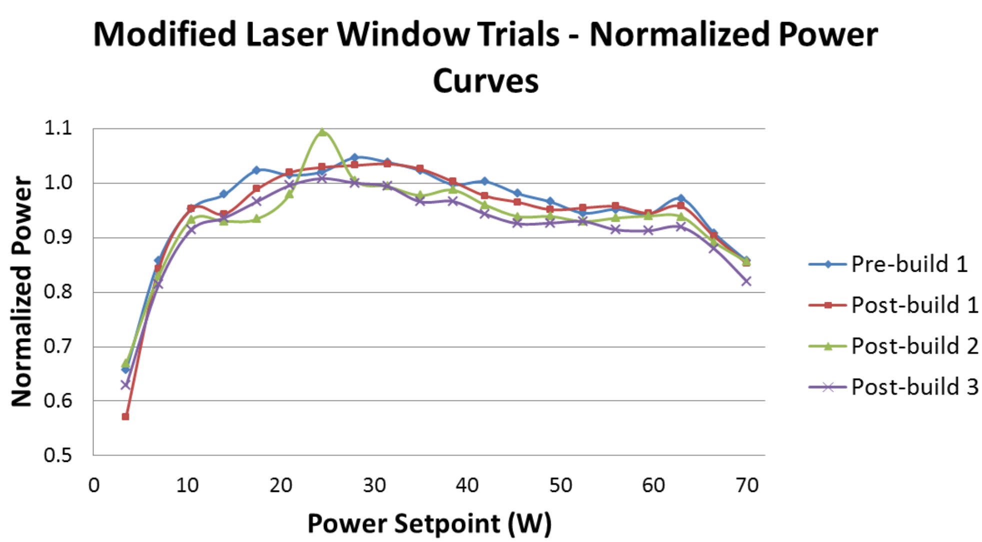


Figure 10. *Nominal and normalized power curves for the modified window housing design*

The plots in Figure 10 show significant improvement in power loss compared to the standard window housing design. Whereas the standard design showed 10% power loss after the first build, the modified design shows anywhere from 0-3% power loss after the first build. Further comparison between the two designs is made in Figure 11, where the pre-build 1 and post-build 3 power curves for each design are overlaid. After three builds using the original design, a 20-25% power loss is recorded, whereas a 3-5% power loss is recorded for the modified design. A final visual comparison can be seen in Figure 12, where the window from the original design is noticeably dirty after the third build, while the window from the modified design is much cleaner after the third build.

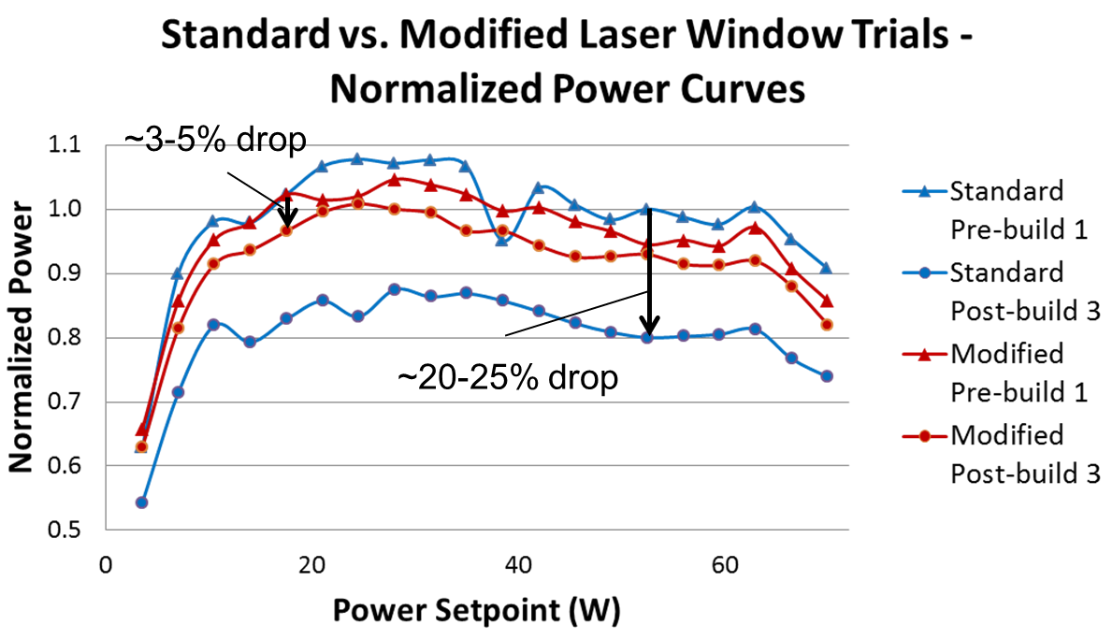


Figure 11. *Standard design and modified design power curves overlaid*

Figure 12. *Visual comparison of original and modified designs after third build*

5. Conclusions and Further Work

Residue buildup on the laser window during laser sintering causes significant changes in laser characteristics at the part-bed, decreasing power and widening the intensity profile of the beam. Residue forms on the laser window when the feedstock materials outgas various substances which condense upon contact with the laser window. A new design was developed to heat the laser window so as to prevent condensation, and subsequently prototyped and tested with promising results. By holding the air between two laser windows to 125 °C and running a 47 hour build using ALM FR-106 material, much less power was lost than in the original design. After three builds and 112 hours of build time, the new design caused a decrease in power of 3-5%, whereas the original design caused a decrease in power of 20-25%.

Further research is needed to identify the gasses present in the build chamber that condense on the window, so as to fully understand how to keep them from condensing. In addition, further testing will be performed at higher temperatures in an effort to prevent gasses with higher condensation points from forming residue on the window.

References:

[1] M. Yuan and D. Bourell, “Efforts to Reduce Part Bed Thermal Gradients during Laser Sintering Processing,” in *SFF Symposium Proceedings*, 2012.

[2] “Multizone Heater System For Selective Laser Sintering.” [Online]. Available: http://www.integra-support.com/docs/MultiZone_flyer_web.pdf. [Accessed: 08-Nov-2013].

[3] C. L. Beyler and M. M. Hirschler, *SFPE handbook of fire protection engineering*. National Fire Protection Association, Society of Fire Protection Engineers, pp. 1-118, 1-119.