A Sieve Feed System for the Selective Laser Sintering Process

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A sieve feed system has been designed for use with the Selective Laser Sintering process. The sieve feed system uses electrostatic charge to help apply polymer powder to a green powder bed. The sieve feed system was found to help the application of polymer powder as measured by a 10 to 15% increase in final part density. The sieve feed system has many potential applications, including material property design, and material mixing during the sintering process.

Introduction

The sieve feed system is an electrostatic apparatus designed to aid the application of powder to a powder bed for Selective Laser Sintering. The system consists of an electrically grounded or charged sieve that powder is forced through during powder application. Once the powder is applied to the sintering surface, it is leveled with a roller or squeegee.

A theory, the sieve hypothesis, was generated to characterize the expected outcome of this experiment. The sieve hypothesis states that sintered parts made from powder applied with the sieve feed system will be more dense than parts made from the traditional roller feed system, and this difference is due to static electric charge in the system. A second theory, the green bed densification hypothesis, states that increased part density from the sieve feed system is due to increased green bed density.

Three experiments were performed using the sieve feed system to determine its effects on the powder system. The rolled polycarbonate experiment, consisting of parts produced with powder applied using the sieve feed system compared to parts produced with power applied using the roller feed system, was the first experiment. A bed density experiment was then performed to prove the correlation between green bed density and sintered part density. The third experiment was an electrically isolated sieve experiment that isolated the sieve from charge and ground to show the effect of static electricity on powder bed packing..

Rolled Polycarbonate Experiment

The first experiment, the rolled polycarbonate experiment, was a single layer experiment using the roller feed system in the Bambi sintering station to apply powder using the traditional Selective Laser Sintering application method. The experiment also produced sieved parts for comparison with roller applied parts. The experiment collected strength, density, change in width (ΔW), and change in length (ΔL) data. All presented data is significant in a 95% confidence interval unless otherwise noted. The experiment used single layer pull test bars to evaluate the sieve hypothesis.

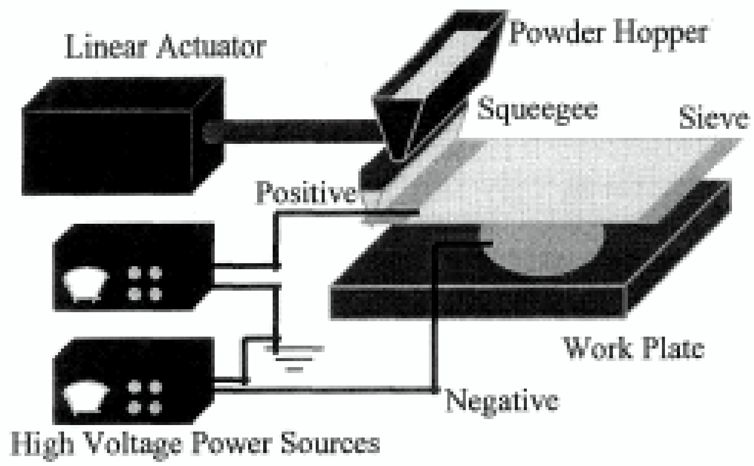


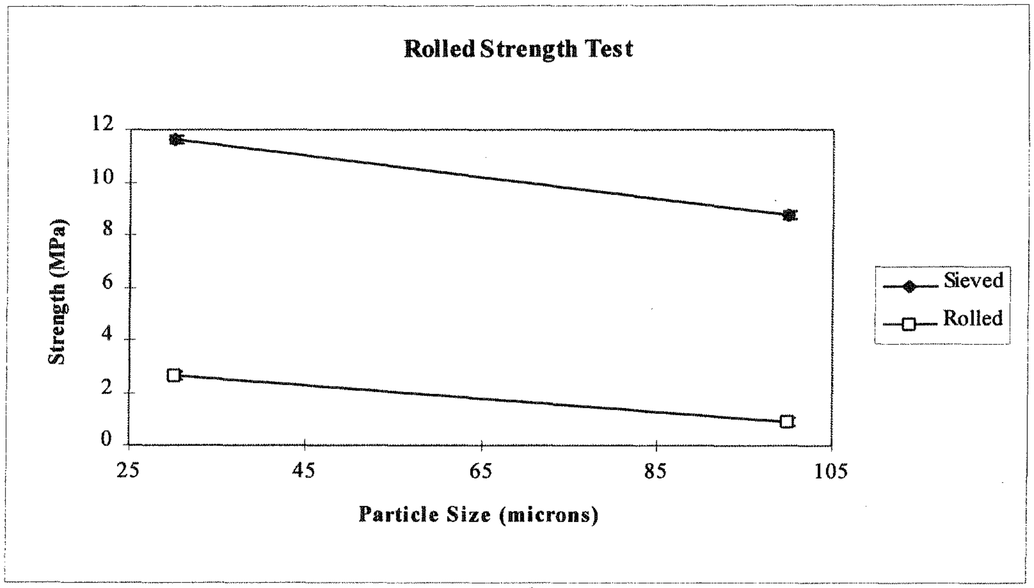
Figure 1
Prototype Sieve Feed System

An example of the experimental sieve feed system is depicted in Figure 1 above. During these experiments, the workplate was preheated to 115°C to reduce curl. The experiment varied the powder application method (Sieve, Roller) and particle size (100 μm, 30 μm). The sieve voltage (0 V), laser power (9 W), plate voltage (0 V), and scan speed (4.23 m/s) were held constant throughout the rolled polycarbonate experiment. The experiment consisted of 2 runs of 5 parts at each set point, resulting in 8 runs and 40 parts.

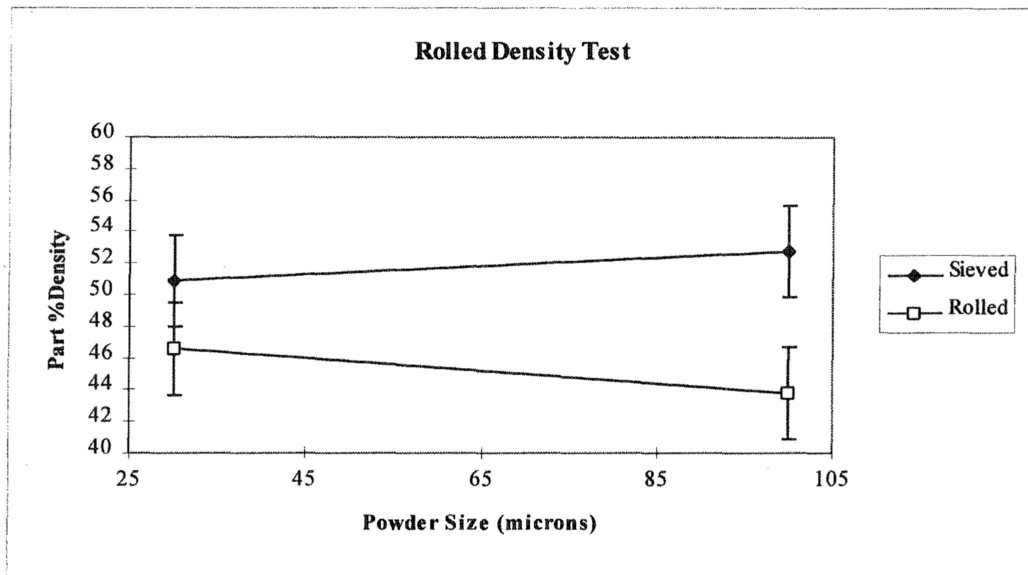
Data from the rolled polycarbonate experiment are presented in Graphs 1 through 3 below. In this experiment, the application method was found to be a conclusive factor in the density, strength, and ΔW analysis of the data. ΔL had significant contributions from the particle size and application method-particle size interaction, while the application method by itself was not significant until the 90% confidence level. This experiment is charted over powder size because low power (7 W) roller applied polycarbonate could not be sintered well enough to create parts that would hold together during the break-out and analysis phases of the experiment.

Property	Particle Size	Application	PS*AM	Error
Density	-	87.85%	-	12.15%
Strength	10.71%	88.90%	-	0.36%
ΔW	-	90.45%	-	9.55%

Table 1
Rolled Polycarbonate Variance of Effects About Experimental Mean

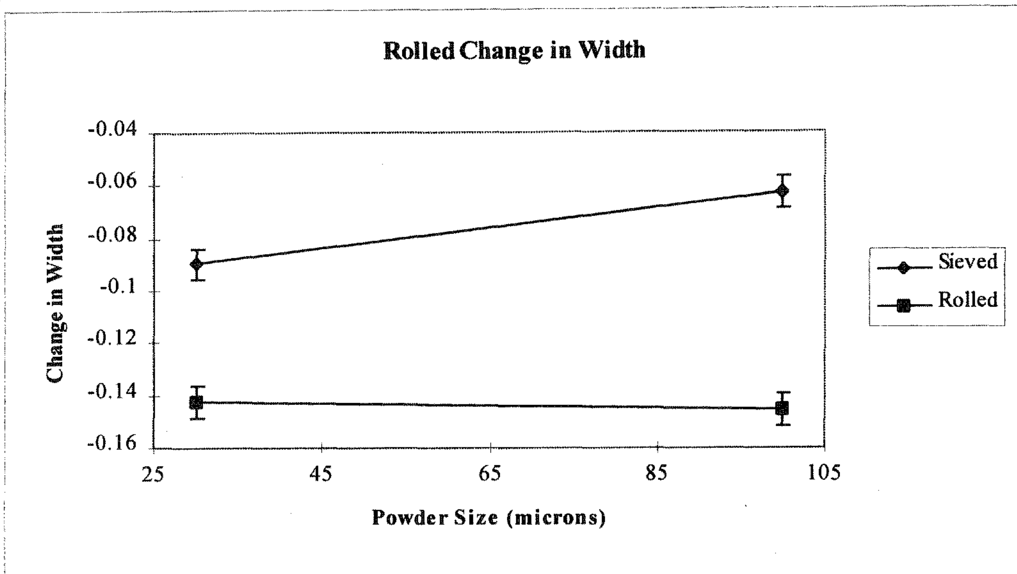


Graph.1
Rolled Polycarbonate Strength Data Plotted Against Particle Size



Graph2
Rolled Polycarbonate Variation in Percentage of Theoretical Density

The information tabulated in Table 1 above is the ANOVA analysis of the effects from the rolled polycarbonate experiment. The percentage refers to the amount of variance about the mean property value that is attributed to the particular effect, with a dash (-) representing no significant contribution. Particle size is self explanatory, while application refers to the application method effect and PS*AM is the particle size-application method interaction effect, and error is the amount of variance that may be attributed to random error. It is clear from this table the application method effect dominates all three part properties.



Graph 3
Rolled Polycarbonate Variation in ΔW. Notice Slope of Sieved Particles.

The important trend in the rolled polycarbonate experiment is the improvement of powder properties when delivered by the sieve rather than the roller. The strength and density analyses of the application methods demonstrate significant improvement in the respective properties. It is also important to note that the sieve ΔW data in Graph 3 significantly demonstrate better dimension holding characteristics than the rolled polycarbonate.

To validate the rolled polycarbonate data, polycarbonate density and strength data were obtained from J. C. Nelson at DTM Corporation for comparison. The Nelson data used a particle size of 90 μm and multilayer parts which were 3.18 mm thick. The Nelson data is comprised of a best fit line between experimental data points:

$$st = 60.64\,\rho - 26.26, \qquad 1$$

where *st* is the ultimate strength of the polycarbonate part and ρ is the part's density. A linear equation was then written for the small particle data points:

$$st = 182.22\,\rho - 81.23. \qquad 2$$

An equation was also written for the large particle case:

$$st = 77.5\,\rho - 31.58. \qquad 3$$

All of these equations state that when relative part density is zero, the part will have a negative ultimate strength. This means the parts will not hold together at and below some density. This critical point, *st*=0, is at ρ=0.433 for equation 1, ρ=0.445 for 2, and ρ=0.407 for 3. As these numbers are relatively similar, and given the differences in the experiments, a good correlation may be judged to exist between these experiments.

The comparison of the Nelson data and the rolled polycarbonate data shows the large particle data correlates well with external experiments. However, the small particle data do not correlate with the Nelson data. Because the Nelson data used multilayer parts, the ≈20% difference in the equations is acceptable. The disagreement between the Nelson data and the small particle rolled polycarbonate data cannot be adequately analyzed because of the difference in particle size; 90 μm volume average diameter for the Nelson data, and 30 μm mass average diameter for the rolled polycarbonate data.

The sieve hypothesis has been proven with the rolled polycarbonate experiment. Overall, the sieve feed system outperformed the roller feed system in the strength, density, and change in width analysis. Also, the sieve feed system was able to sinter polycarbonate with a lower laser power than the roller feed system.

While an increase in strength and density are the desired outcomes of employing the sieve feed system for powder application instead of the roller feed system, the shape change data is the most interesting. The ΔW data for the sieved system has almost half the amount of shrink than is present in the rolled system. It is also intriguing that ΔW data remained constant over the range of particle sizes in the rolled system. The fact the sieve feed system produces better part densities with less change in part width implies that the green powder bed is more dense in the sieved case.

The constant shape change (ΔW) over the range of particle sizes in the roller case suggests that inhibitions of green bed density are more easily removed from larger particle sizes than from smaller particle sizes in the sieve feed system case. Literature sources state that powder particles tend to accumulate a static electric charge while they are being processed and handled [Masuda p. 283]. The sieve feed system seems to be able to remove some of that static charge from the particles as they are forced through the sieve, and thus remove the static charge inhibition to green bed density.

The sloped line from the shape change data in Graph 3 indicates the larger powder particles may have more of their static charge removed than the small particles. Both particle sizes were applied with the same 150 μm sieve, which could lead to different amounts of charge removal for different particle sizes. In the small particles case, with mass average 30 μm diameter, an average of 25 particles could fit through one sieve opening, while the large particles, which mass averaged 100 μm diameter, could only average one particle through the sieve opening at a time. These geometric limitations imply that large particles will almost certainly be in contact with at least one wire in the mesh and thus some of its surface charge could be bled off. However, the small particles will not necessarily come in contact with the sieve. Since they are polymers that do not readily conduct charge [Mark], only some of the particles forced through the same sieve opening will contact the sieve mesh and lose charge as they are applied with the sieve. This analysis indicates the sieve must be properly sized to effectively discharge a particle: The smaller a particle, the smaller the necessary sieve openings.

Polycarbonate Bed Density

This experiment was designed to explore the relationship between green bed density and final part density. It examines known green bed densities and measured final part qualities. The data will be used to understand sieve feed system bed densification mechanisms and evaluate the green bed density hypothesis.

This experiment was run using a bed density device built by Nathan Moore at the University of Texas at Austin and depicted in Figure 2 below. Polycarbonate powder was packed in three densities and run under two laser powers. The parts were run with variable laser power (9 W, 11 W), and bed density. The scan speed (4.23 m/s) was constant. No preheat was used in this experiment due to the thickness of the bed filling the density tool. This experiment employed set points that do not readily translate into the other polycarbonate experiments.

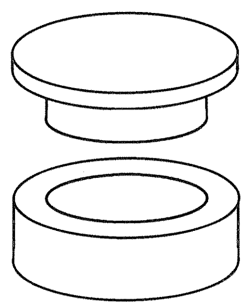
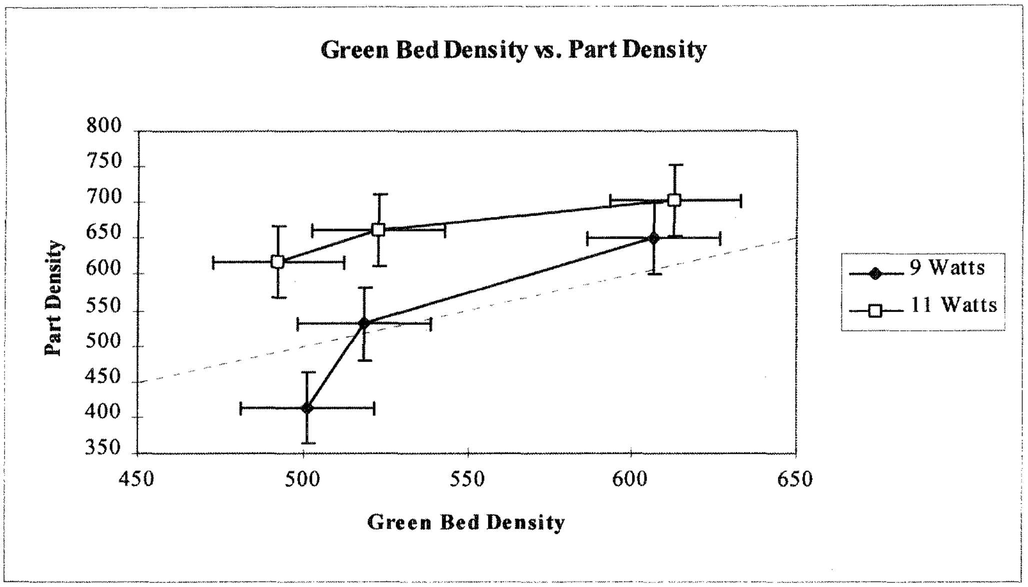


Figure 2
Bed Density Tool

The bed density was set for the first run by filling the bed cup with polycarbonate and leveling it. The second test was run using the weight of the top to compact the powder, thereby producing a larger green bed density. The whole apparatus was placed in a vise and compacted for the third test, which produced the largest green bed density. The bed density was calculated from the distance the top of the tool was depressed into the powder bed and the mass of the material in the bottom of the tool. Due to the small size of the apparatus, only three parts could be made per run. The experiment consisted of six three part runs for a total of eighteen parts.

Three data points have been used in this experiment because green bed density must be varied too greatly to validate an assumption of linearity. The dashed line through Graph 4 below is the equilibrium line where bed density and part density are equal. The important trend to observe from this experiment is that part density increases with increasing bed density. It is also interesting to observe the Selective Laser Sintering process may produce a part that is less dense than the green bed density in some cases. This unusual phenomenon is theorized to be due to incomplete sintering that allows particles trapped in the part during sintering to fall out when the part is handled and analyzed.



Graph 4
Final Part Densities Produced From Known Green Bed Densities

The data from the rolled polycarbonate experiment have shown the final sieved parts are better in quality than the final rolled parts. The data from the green bed density experiments show a correlation between green bed density and final part density. Although no direct green bed density measurements of sieved green bed densities have been performed, the green bed density experiment demonstrates that green bed densification is a mechanism of increased final part density. The reason the sieved parts are better than the rolled parts now may be theorized to be the sieved green bed density is larger than that of the rolled green bed.

Nonconducting Sieve

The purpose of the nonconducting sieve experiment is to determine the effects of the sieve feed system on statically charged polycarbonate powder. This experiment isolated the sieve electrically from ground during powder application to avoid removal of static charge from the powder by the sieve.

This experiment was run in single layers with 100 μm polycarbonate powder, and with the workplate preheated to 115°C. Three sweeps of powder were made to the side of the part cylinder while wearing rubber gloves, then the sieve was placed over the part cylinder and the powder was applied. The experiment varied the laser power (7 W, 9 W) and sieve voltage (0 V, electrically isolated) while holding the scan speed (4.23 m/s) and plate voltage (0 V) constant. The experiment consisted of eight runs of five parts each for a total of forty parts.

The nonconducting sieve experiment was compared to roller feed system parts and grounded sieve feed system parts. The final data show that parts produced with the roller feed system and the electrically isolated sieve feed system have the same density properties, within experimental error. The roller feed system produces a part of density of 554 kg/m^3 or 46.2% dense while the nonconducting sieve feed system produces a part of density 560 kg/m^3 or 46.7% dense.

The nonconducting sieve experiment demonstrates that final part density of a part manufactured with an electrically isolated sieve is the same as final part density of a part constructed with the roller feed system. One known green bed density inhibitor is static charge in powder[Knudson et. al. p. 234]. Therefore, as the sieve was unable to remove charge in this experiment, it may be concluded that the sieve feed system increases green bed density by removing static charge from the powder.

Conclusions

The sieve hypothesis, which states that a sieve feed system will improve final part quality over the standard roller feed system, has been accepted. The mechanism of this final part quality improvement appears to be green bed densification through the removal of static electric charge from the system. The green bed densification hypothesis stating that part quality increase is due to densification of the green powder bed is also accepted. The data show that green bed densification is the only known effect operating on final part quality. The mechanism of this effect is theorized to be removal of static charge.

The rolled polycarbonate experiment has shown the sieve feed system final part quality is better than that of the roller feed system. The final sieve part strength is 3-5 times better, final sieve density is better than the rolled part density by 5-10% relative density, and the sieve width shrinks half as much as that of the rolled part. The green bed density experiment has shown that part density will increase with an increase in green bed density. Data from the nonconducting sieve experiment show the electrically isolated sieve produced the same density value as the roller feed system, thus demonstrating that charge removal contributes to part quality.

Sources

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