Solid Freeform Fabrication 2017: Proceedings of the 28th Annual International
Solid Freeform Fabrication Symposium – An Additive Manufacturing Conference
Reviewed Paper

Influence of the Ratio between the Translation and Contra-Rotating Coating Mechanism on different Laser Sintering Materials and their Packing Density

L. Meyer, A. Wegner and G. Witt

University Duisburg-Essen, 47057 Duisburg, Germany
lars.meyer@uni-due.de

Abstract

An initial study about the advanced machine parameters and their impact on the packing density of different laser sintering materials was conducted on a self-developed laser sintering machine. Usually, on commercial machines, the ratio between the translational and contra-rotatory movement of the roller is fixed. The standard ratio is established for polyamide 12, but new materials, such as polyamide 6 or polybutylene terephthalate, need adjustable parameters to find optimized composition coating results. In the testing machine, the contra rotating roller can be replaced by a coating blade to generate the powder layers. In Addition to the tests with the roller, two different shapes of coating blades were tested. This allows a comparison between both commercial coating systems in laser sintering machines.

Introduction

Laser sintering is a technology that enable users to produce three dimensional parts from powdery material. To realize a freeform production, sliced CAD parts are built additively layer by layer and generate physical components. This process contains three steps that repeat until the build process is finished. The generation of the single powder layer is the first step of the whole process. So, this step should work solidly and precisely. After this the actual part-profile of the part is generated by a CO_2-Laser. The third and last recurrent step is the piston lowering of the supply thickness.

The generation of a new powder layer with common materials, such as polyamide 12, was usually processed by a contra-rotation roller or a fixed blade [1 bis 4]. The use of a roller- or a blade-system depends on the machine and the manufacturer. The different coating systems have different influences on the packing density. Nevertheless this factor is one of the most important for a stable process, high part density and the dimensional stability of the parts [5, 6]. In [5] a twostep coating system was evaluated. In the first step, a thicker coat as needed was created. In the second step, the piston rises up again, so the powder gets compressed by a rotating roller. In [7] the ProX™ 500 is presented as a commercial system, that works with a contra-rotating roller with variable parameters for the rate of rotation. Due to this, the ProX™ 500 describes actually the state of the art in contra-rotating coating systems. The coating systems are designed for polyamide 12, which represents nearly 95 % of the used materials in additive manufacturing [3]. In future, it is predicted that the material selection will grow and allow the user to build parts in many different polymers [8]. Due to the different behavior of the new materials, more flexible parameters are going to be needed that have influence on the packing density. Usually, on commercial machines, the ratio between the translation and contra-rotatory movement of the roller is fixed. Furthermore, the roller is designed as a coating system for polyamide 12. There are no flexible parameters for other material systems, that come out into the market. Because of this the focus on this paper lays on the optimization of generating a powder layer with high packing density based on the switch of the contra-rotating speed of the roller. The roller system has two variables: The translation and the contra rotating speed. In addition to that, the coating system has been switched into the blade system with two different blade geometries. Based on the results of the commercial machine they were used as a sampling point and show the potential of higher packing density that could be reached in roller-based coating systems.

Methods

The commercial machine represented is a DTM 2500 HS. Although the DTM has a high-speed-upgrade, the coating system has not been changed. There are still many machines of this type or based on this type used in production for additive build parts. It has an installation space of 340 x 280 x 400 mm³. The ratio between the translation and the contra-rotation is fixed by a toothed rack. The used translation speed v_{trans} is constant at about 127 mm/s and describes the standard parameter on this machine. Based on 4/9 rounds per second and a roller diameter of 76.25 mm the circumferential speed, called rotation speed (v_{rot}) is about 106 mm/s. As shown in figure 1, the resultant speed of the roller coating system depends on the surface of the roller, that is in contact with the created powder layer. The effective speed v_{res} composes of v_{rot} plus v_{trans}.

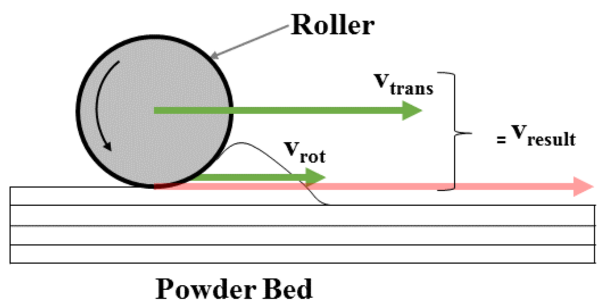
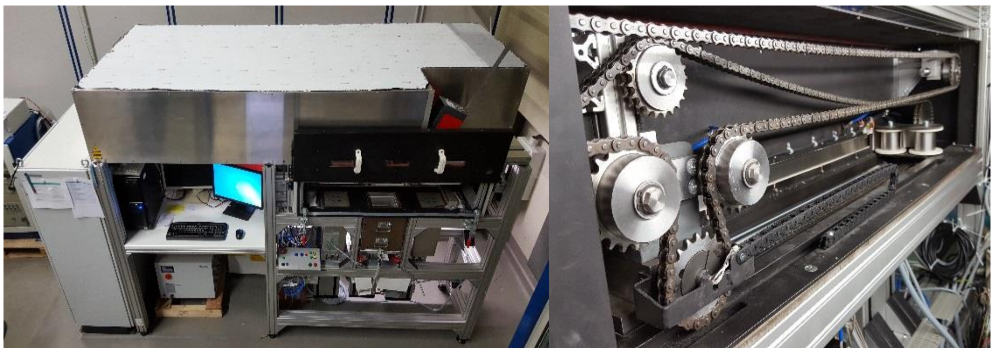


Figure 1: Resultant speed of the roller coating system with contra rotating movement

Based on the v_{res} of the DTM 2500, the sampling point is defined at 233 mm/s. During the experiments on the self-developed machine, v_{trans} is constant about 127 mm/s while v_{rot} is changed. Further, another attempt based on the same rate of rotation was realized at 189 mm/s on the self-developed machine. Due to the possibilities and the visual evaluation an unsteady screening venture between the range of 140 – 607 mm/s was conducted.

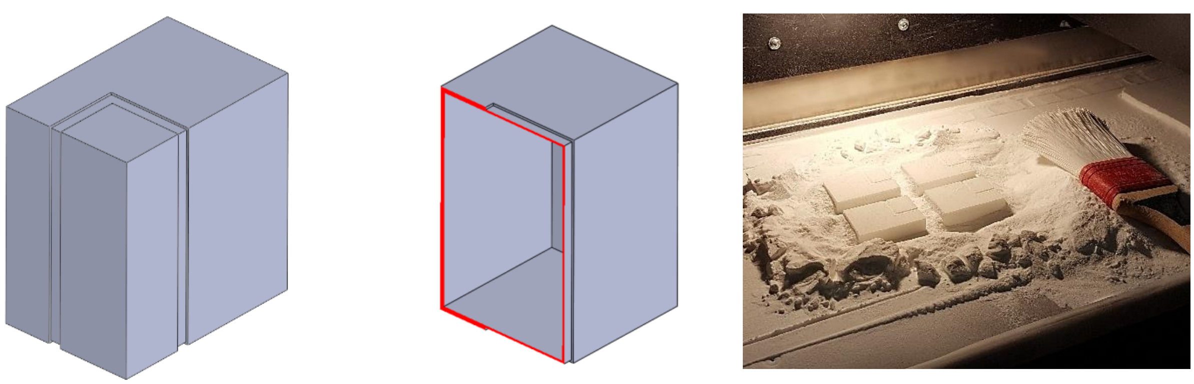
At the Rapid Technology Center (RTC) in Duisburg, a self-developed laser sintering machine has been built. The focus is on the complete variation of parameters by all accounts. The minimization of non-productive time and faster part-profile creation shows great potential for the high-performance production of plastic parts. This is a way to reduce the cost of additive manufactured parts by increasing machines throughput [8]. The self-developed laser sintering machine is among other specifications characterized by a variable coating system. It contains variable rotation speeds, different rotating directions, a heated roller body and a wide range of 50 – 480 mm/s translation speed. Moreover, the roller can be replaced by a blade system, with a slot for two different kinds of blades: A rounded or a flat one. Due to this changing system that allows a comparison between the coating systems, the machine immanent influence can be identified. As shown in figure 2 b), the separation of the translation and contra-rotation speeds is realized with two engines. The gearbox is designed for temporary temperatures above 180 °C (356 °F). For this reason, the engines were installed outside the gearbox while the transmission is realized by chains. The translational chain is a duplex chain, that makes a parallel kinematic engine possible and promotes a silent running on the friction bearings along the linear unit. The designed installation space is about 190 x 140 mm with a height of 250 mm. A replaceable build container allows to build more jobs in close succession. To guarantee a failure-free operation during the shift, the container is thermally isolated and can be pre-heated outside the laser-sintering machine. While the first container is cooling down, the second one can be in use. This way of proceeding allows building as long as the feeds are filled with powder.



a) Front view *b) Gearbox*

Figure 2: Self-developed laser sintering machine at the RTC-Duisburg, Germany

The packing density sample is a hollow box as shown in figure 3. The inside measures are 30 x 45 x 45 mm (1.18 x 1.77 x 1.77 “) with a volume of 70.875 mm^3 and a wall thickness of 1 mm. This bigger size of the sample has been chosen to minimize the effect of the powder adhesions on the surface. Further the height of 47 mm represents a solid processing.



a) CAD-file of the sample *b) Sectional view* *c) After successful build-process*

Figure 3: Packing density sample

After the container is successfully built, it contains the powder inside and gives a value by weight of (m_f) the difference between the full sample and the empty one after blasting with glass balls (m_e).

The difference between m_f and m_e results in the weight of the powder as a bulk weight (m_B). By measuring the container's inner volume (V_C) and using equation 1 the bulk density can be reckoned [9].

$$\rho_B = \frac{m_B}{V_C} \qquad (1)$$

The bulk density is the first step to get the information of the packing density. To transfer this qualitative value into a quantitative one, the highest theoretically possible density of a solid part should be used. The packing density is reckoned by using the density of a solid part (ρ_S) as shown in equitation 2.

$$\rho_P = \frac{\rho_B}{\rho_S} \qquad (2)$$

The sample is constructed with a predetermined breaking point to open it easily with a scalpel. Due to the usage of the scalpel, chipping is prevented and allows an exact measurement. The inner measurements were realized by a sliding caliper within a resolution of 0,01 mm. Every measurement was realized three times to generate a mean value. The appointed weighting scale has a resolution of 0.001 g.

Each experiment on the self-developed laser sintering machine includes four samples distributed consistently along the corners of the installation space. For each resulting speed one build job was realized. In total twelve build jobs, one on the DTM 2500 HS and eleven on the self-developed machine were conducted. On the DTM 2500 HS, there were nine samples as a 3x3 matrix over the installation space distributed. All samples were measured and created the mean value with the standard deviation. The powder used is a mixture of EOS PA 2200 powder, that contains 50 % new and 50 % recycled powder. To check the same quality-level in each sample, the melt-flow-rate has been continuously observed.

In a second step, a visual testing of different powder materials was conducted. The materials systems that are chosen were a polyamide 6 (PA 6) and a polybutylene terephthalate (PBT) powder. The Sinterline™ PA 6 is distributed by Solway Cie S.A. and is made up of milled PA 6 granulate. Polyamide 6 or Polyamide 6/6 amounts over 50 % of the polyamide production worldwide and is a standard polymer in other industries such as injection molding [10]. Due to this, a solid laser sintering processing based on flexible parameters could help to establish this material and represent the characteristics of real production parts. Another chosen material is a polybutylene terephthalate without any additives and a particle size distribution about 0 – 125 µm. This material was chosen because of the difficulties of generating a powder layer with a standard machine.

The experiments were conducted at room temperature because of the maximum operation temperature of the edge light. Used roller and blade speeds are the same values as in the packing density specimen. A Canon EOS 40 D digital camera with a resolution of 10 megapixel and a Ø 67 EF-S 17 – 85 mm objective was used under edge light to get a visual feedback of the powder bed surface. The pictures in table 1 and 2 shows a 20 x 30 mm² section of the powder bed surface after a new layer powder has been deposited.

Results

Packing Density of Polyamide 12 with a Roller

To reckon the packing density, the references gives different values for the solid density. While [10] gives a value of 1.01 g/cm³, [11] gives 1.02 g/cm³. Based on a solid density of 1.01 g/cm³ the results of the DTM 2500 HS are shown in figure 4. The average packing density is 41.34 % with a standard deviation of ± 0.39 %. Noticeably are the high values in the corners in three of four cases. The middle and the positions between the corners have lower values. That could be affected by different powder pressures during the generation of a powder layer. While generating the next layer at the beginning of the supply, thickness the powder feed transported by the roller is bigger than at the end of the layer. Due to the higher pressure, the powder could get temporarily more compressed and influences the value of the packing density. If the feed is the same on both sides of the machine, and the pre-compression was the same, this influence would be in symmetrical disposition over the installing space. Provided the pre-compression is not the same, or the feed lifts on one side more than the other, these effects on the values are not reproducible. Another reason could be geometrical differences of the roller. If the surface of the coating mechanism is not cylindrical, there could be zones in the powder bed that gain a higher compression factor than the other zones. Based on the fixed ratio of the contra-rotating movement, these effects would be permanently at the same position in the installing space. The lowest level of packing density of 40.704 % is reached in the right front corner. With 41.93 %, the highest level is reached in the other right corner in the back of the installation space. Both values are out of the standard deviation but inside the double deviation. So, they should not be viewed as outliers.

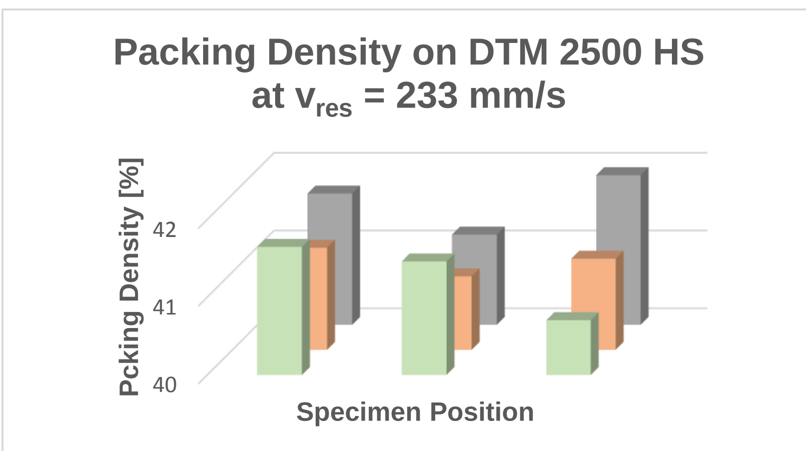


Figure 4: Symmetrical distribution of the packing density on the DTM 2500 HS

Due to this, the nine samples are representative. The DTM 2500 HS reached a maximum packing density of 41.34 %, which is lower than other presented results [6, 12, 13]. This could be due to the effect of different specimen dimensions and the lower influence of the part surface.

Based on the discussed sampling point, the coating mechanism of the developed laser sintering machine was equipped with the contra-rotating roller. The first step was to find a sampling point that represents the achieved packing density on the DTM 2500 HS. Two speeds were conceivable:

The resulting speed at the tangential surface of the powder and the roller (v_{res} = 233 mm/s), or the same rate of rotation as in the standard machine (v_{res} = 189 mm/s). Figure 5 shows the results of these two possibilities in comparison to the reached packing density at the DTM 2500 HS. In case of the higher v_{res} the packing density reached a value of 42.14 % ± 0.25 %. Lower v_{res} results in higher packing density. 189 mm/s gains a packing density of 43.04 % ± 0.28 %. The value of the DTM 2500 HS is marked as a red line and shows the lower value of 41.34 ±0.38 %. From this it can be concluded, that the approach of using the resulting speed is more in consensus than the rotating number. Even with consideration of the standard deviation there is no quantitative consensus in the packing density values. The self-developed machine gains packing densities on a higher level. This could be an effect caused by the different roller designs. The roller of the DTM has a diameter of 76.25 mm and the surface is rough. The roller of the developed machine has a diameter of 45 mm while the surface is smooth. Even when the same resultant speed is used, the smaller diameter of the roller could affect a higher compensation caused by a smaller zone of interaction.

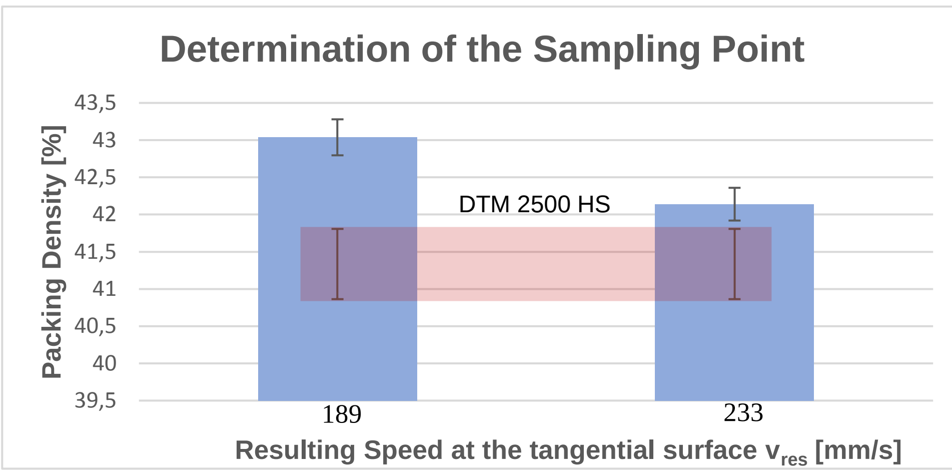


Figure 5: Sampling point of the self-developed machine to the commercial machine

Another conclusion is, that lower resultant speeds of the coating mechanism could gain significantly higher packing densities. It is recognizable that v_{res} = 189 mm/s gains 0.9 % higher values at the expense of process stability. Further experiments were conducted to find a stable process with reproducible results in high packing densities.

At this stage, the slowest conducted resulting speed was 189 mm/s. By a visual checkup a step to v_{res} = 153 mm/s was realized. This results in a difference of 36 mm/s, so the next lower step was set on 225 mm/s. Figure 6 contains the results that show a high packing density of 43.97 ± 0.25 % at the speed of 153 mm/s. In comparison to this, the 225 mm/s still gains a value at 42.6 ± 0.28 %. In accordance to the theory that slower resulting speeds gains higher values the results verify this.

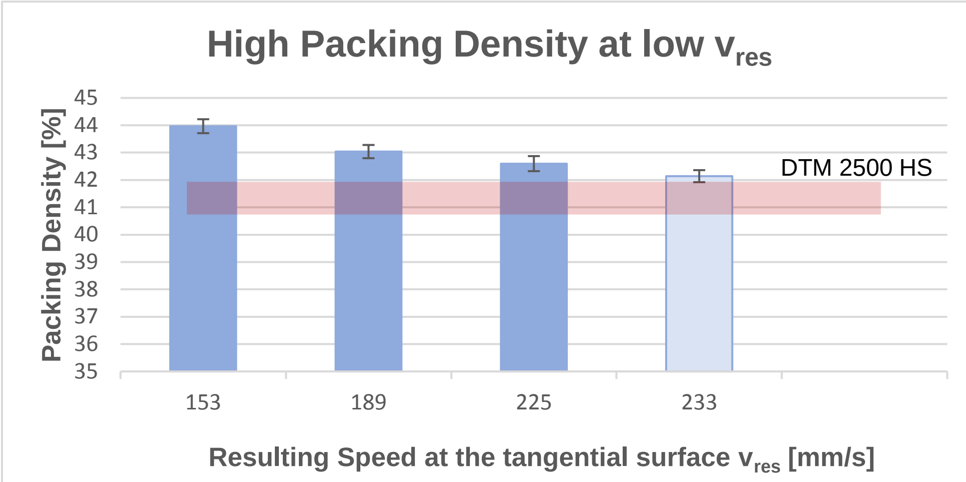


Figure 6: Higher densities at power speeds

For the orientation, the figure shows the sampling point including the standard deviation as a red line and the sample point with 233 mm/s too.

By analyzing the higher densities it can be concluded that the values of the packing densities are an inverse result of the contra rotating speeds. By changing the ratio between translation and contra rotation we could gain 1.8 % higher packing densities including the machine immanent characteristics and even 2.63 % higher values compared to the sampling point.

To come next, the minimal contra rotating speed with a finely ground of powder layer was realized at v_{res} = 140 mm/s. Below this value of the rotating speed, the powder surface gets flaws and would result in unstable processing. Even in progressive processes, two of the four specimens were carried away by the coating system. Due to this, the next value is statistically not proven but gives a forecast of the opportunities in the future. The gained value for the packing density is 44.64 %. That value implies a higher packing density of 2.5 % on the same machine and even 3.3 % higher than the sampling point based on the commercial machine.

As the minimum v_{res} with stable process behavior is found out as 153 mm/s, there could be a maximum v_{res}. To figure out if the correlation between slower speeds and higher packing densities is continuous, faster v_{res} were tested. By visual checkup 36 mm/s steps from 225 mm/s were conducted. Individual testing points were figured out in this step range until a v_{res} of 555 mm/s. At last, the maximum v_{res} with a value of 607 mm/s was conducted. The results of this screening are pictured in figure 7. The values of the packing density are continuously under the sampling point, represented as the red line including the standard deviation. The lower level of packing density had a few effects on the process stability. As you can see, the two fastest v_{res} show higher standard deviations than the others. This is largely because of accruing flaws during the process. The lowest value about 37.65 ± 0.51 was gained by v_{res} = 555 mm/s. Even the most rapid v_{res} of 607 mm/s obtained a higher value of about 38 % with a lower standard deviation of 0.37 %.

It is generally valid that lower v_{res} speeds result in higher packing densities and higher speeds result in lower densities. The variation at lower density levels is much higher, so temporarily some higher resulting speeds gains higher packing densities. But these effects only exist in lower density levels.

These lower levels should be avoided and have no importance in industrial applications, due to the instable process behavior.

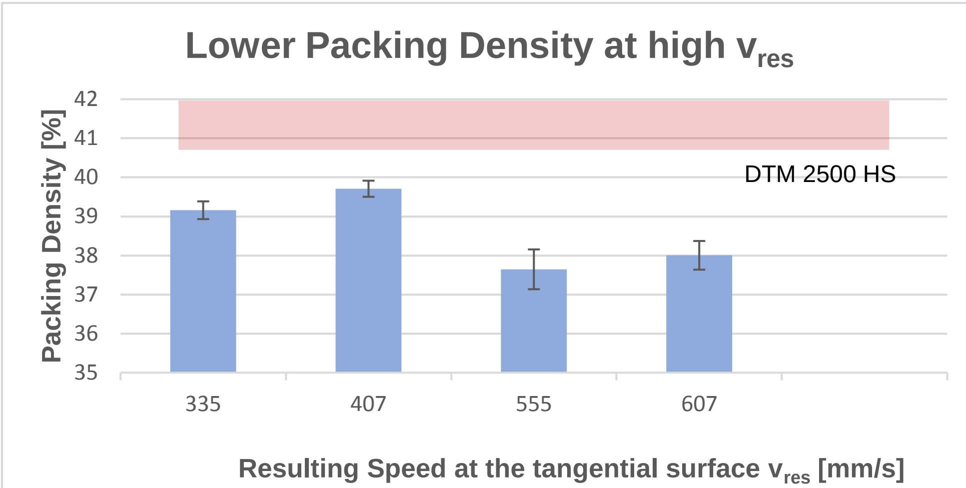


Figure 7: Lower densities at higher speeds

As an interim conclusion, the experiments show a high dependence of the ratio between the translation and rotation speed as a function of the packing density for polyamide 12 powder. Further, an optimized ratio based on the translation speed of 127 mm/s could be tested and validated. Due to this, the ratio used in the commercial machine is not the best choice, even for the standard material. A comparison of the roller coating and a blade system will show the differences between the coating systems on the same machine. This allows conclusions about the reached packing density and the possibilities of optimization.

Packing Density of Polyamide 12 with a Blade

Based on a static and non-rotating system, v_{res} is the same as v_{trans}. Two different shapes of the blade were used, so that the effects of the geometrical shape are represented. The differences between the rounded and the flat blade are shown in figure 8. The flat blade gained a packing density of about 40.59 % with a higher standard deviation of 0.47 %. This value is under the average of the DTM 2500 but within the standard deviation. Different from this, the rounded shape reached higher packing density. Its value is about 42.4 % with a small standard deviation of 0.029 %.

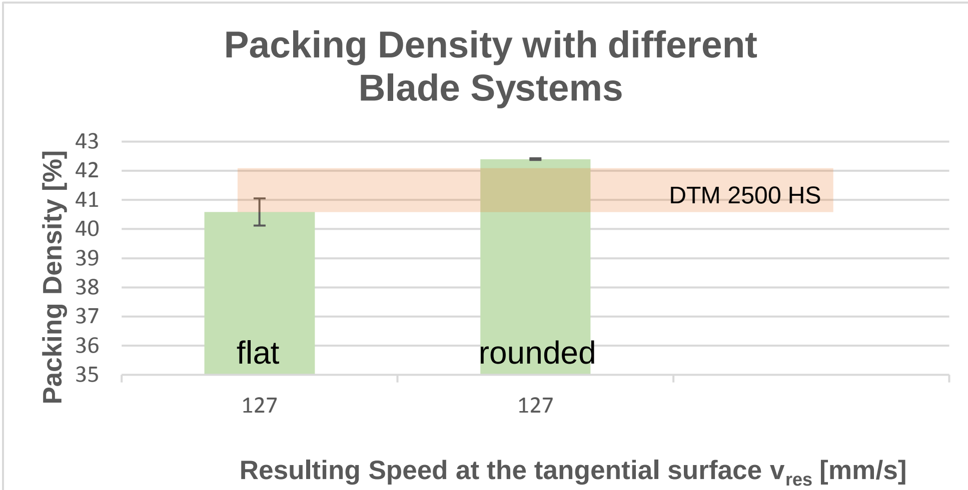


Figure 8: Comparison of two different blade shapes

The low standard deviation of the rounded shape is the smallest in the experiments. From this we can conclude that the rounded blade has a very constant generation of a powder layer, that depends on the geometrical shape. Even the higher value of packing density provides the hypothesis, that smaller diameters at the coating system result in higher compression of the powder and due to this in higher packing densities. Apart from that, the flat shaped blade shows us a packing density at the dimension of the sampling point. With the high standard deviation, the coating system is not able to guarantee a reliable generation of a powder layer at high quality for polyamide 12. This shape could be used for other materials with low flow properties.

Gained Packing Density Values for Polyamide 12

Figure 9 gives an overview of the conducted experiments. The specific values were discussed beforehand. As previously, the red line contains the value of the DTM 2500 HS as the sampling point. The blue bars are the experiments with the ratio of the contra-rotating roller and the green bars represent the blade system with two different shapes. The range of the resulting speed v_{res} on the tangential surface that touches the powder is about 127 – 607 mm/s. Between the targeted step range of 36 mm/s there is a value of 233 mm/s that represents the commercial machine on the self-developed laser sintering machine. The minimum and the maximum of the contra-rotating system are definite as 140 and 607 mm/s whereas the static systems worked continuously on 127 mm/s. The results of the packing density show on the one hand an anti-proportional function for the resulting speed and on the other hand the effects of using different shapes of blades or deduced from this the effects of different diameters of the cylindrical roller.

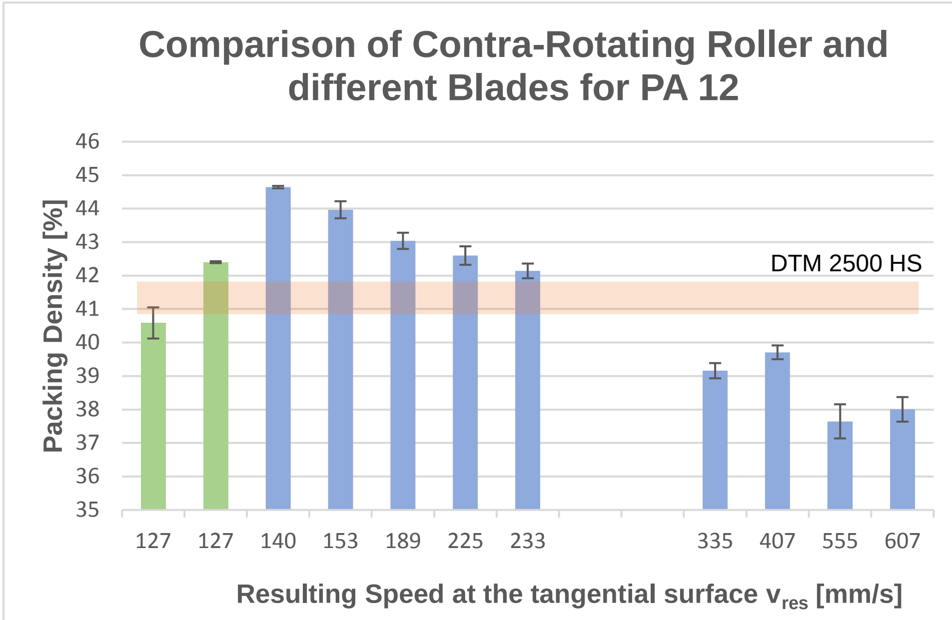


Figure 9: Packing density overview

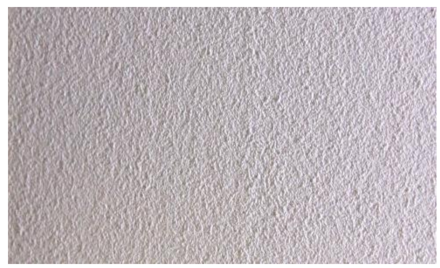
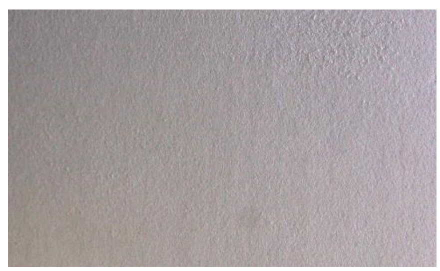
Green: Blade Coating Systems Blue: Roller Red: Commercial Machine

Further, figure 9 contains the proof that the contra-rotating roller system could be optimized. The highest packing density was reached with a slow resulting speed at 44.64 % and a standard derivation about 0.04. With the restriction of getting an unbalanced process in higher layers, the contra-rotating roller gained more than 2.2 % to 4 % higher values than the static blade system. But by considering of the represented commercial machine at the developed laser sintering machine, the blade has some advantages. The design is easy and a static coating system could benefit a solid process. In case of the rounded blade, the gained packing densities are higher at the sampling point than the values of the roller. This result matches with other studies that already compare different types of coating systems [6, 12]. Due to the detection of the high influence of the geometric shape, other shapes could compensate the missing parameter of the contra rotating blade and should be investigated in further studies.

Additional coating tests with different Materials

In the next step, different powder materials were chosen to get a visual feedback of the generated powder surface. The target is always a finely grounded powder bed surface to guarantee a stable process caused by the solid focus location and constant layer thickness. Edge light is used to shadow the surface irregularities and to simplify the visual evaluation. Table 1 contains the results of the experiments with the contra-rotating roller system. The images show a picture detail of 750 x 450 mm² on the powder bed surface. All parameters that were used for the packing density specimens were conducted in these experiments. These results could permit a visual controlling of an optimized ratio during the laser sintering process and would result in higher packing densities. As a reference image, the sampling point was chosen and set on 233 mm/s. In relation to the reference image, the best results are shown with the used v_{res}. Little optimization is observed at the standard material although the surface of the polyamide 12 seems to be smooth in both tests. A better result could be reached at lower resulting speed of the coating mechanism. A finely grounded surface could be realized at a resulting speed v_{res} = 140 mm/s. This test correlates with the results in packing density of polyamide 12. A higher resulting packing density of 2.5 % is detectable by visualization, if the source and position of light is well chosen. The second used material system is a milled polyamide 6 powder. As you can see, the surface at the standard ratio is partly finely grounded. In some areas, the surface gets rough. At the optimized parameters, a lower v_{res} gains a higher quality of the surface in the whole build area. The comparison of the images justifies the suppose, that a higher packing density would be gained in the optimized ratio of v_{res} = 140 mm/s. A different behavior of the material system is shown for the PBT. The texture is similar to powdered sugar. While the standard v_{res} generated many flaws and a rough surface, the higher v_{res} from 335 mm/s and more gained a finely grounded powder bed surface.

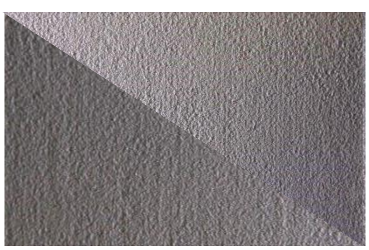
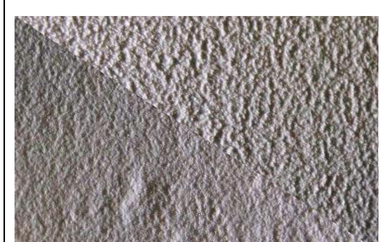
Table 1: Results of the contra-rotating roller coating system on different materials

	Standard	**Optimized**
	v_{res} = 233 mm/s	**v_{res} = 140 mm/s**
PA 12		
	v_{res} = 233 mm/s	**v_{res} = 140 mm/s**
PA 6		
	v_{res} = 233 mm/s	**v_{res} = 335 mm/s**
PBT		

In derogation from the other materials, the PBT's behavior creates a better surface at higher contra-rotating speeds. The reason could be based on in a shorter interaction time with the surface of coating system. Due to this, a higher speed counteracts the high adhesive tendency of the PBA and gains qualitative better surfaces and should reach better packing density in the process, or makes a solid process even possible. For both polyamides, the lower resulting speed results in qualitative better powder bed surfaces. This includes the theory, that a smoother surface would result in a higher packing density. For polyamide 12 this theory is already validated. Next step could be the validation for polyamide 6. The lower speed effects a higher compression on the powder material and leads the powder particles to reorder in a more compact way. This reordering process has positive effects on the packing density including all synergy effects.

Table 2 contains the contrast of the rounded and the flat shape of the blade. Used resulted speeds were the sampling point with 127 mm/s, the maximum with 607 mm/s and the value between these resulting speeds with 367 mm/s. Based on the static system, v_{res} is the same as v_{trans}. As the images contained both experiments, the rounded blade is shown at the lower left zone and the flat one in the upper right zone.

Table 2: Results of the blade coating systems on different materials

	Standard	**Higher Speed**	**Max. Speed**
	$\mathbf{v_{res} = v_{trans} = 127\ mm/s}$	$\mathbf{v_{res} = v_{trans} = 367\ mm/s}$	$\mathbf{v_{res} = v_{trans} = 607\ mm/s}$
PA 12			
PA 6			
PBT			

Polyamide 12 shows at 127 mm/s a finely grounded surface for both shapes. In the case of the rounded blade, the powder bed surface is more consistent. This effect is also included by comparing the packing density in figure 8. The image of polyamide 12 at the resulted speed of 367 mm/s contains a switch of the better surface qualities. In case of the rounded blade, the surface gets rough and small flaws are detected. At the maximum speed, the surface gets cracked and irregular. The flat blade gains better results although it seems not to be qualified for a solid process. Polyamide 6 shows a very similar behavior, except for the quality shift at 367 mm/s. At the resulting speed of 367 mm/s the rounded blade is still more high-graded as the flat one. The quality shift for this material is shown at 607 mm/s. But like polyamide 12, these high speeds seem not to be qualified for solid processing. The PBT shows in very deep flaws every variation through the whole surface bed. This includes the flat shape and the rounded one. While the flat shaped blade shows better surfaces in higher speeds, the rounded one is just the opposite of that behavior. Nevertheless, for the PBT material there is no simple processing to be expected in the case of a blade system.

The comparison of the contra-rotating roller and the blade system shows the needs for a various adjustment of the coating parameters for some material systems. Static coating systems, like the blade, are good in the application for the designed material. If there are new materials the user wants to fabricate, the contra-rotating roller could be helpful but only if the ratio between the translation and rotation is separately adjustable.

Discussion

The influence of the machine was determined at the sampling point. Due to this it can concluded that the diameter of the roller has an influence on the packing density. A smaller diameter of 45 mm gained 0,8 % higher packing density than the diameter of 76.26 mm. This influence is little in comparison to the resulting speed of the roller, which has a strong influence on the packing density. The results point out, that lower resulting speeds lead to higher packing densities. The lowest resulting speed was realized at 140 mm/s and gains 3.3 % higher packing densities than the standard parameters. Supposed the tamp density of polyamide is the best gainable result for the compression of polyamide 12 powder. Based on conducted tests this tamp density is at 51.8 %. The optimized packing density reached with 44.64 % almost 86.1 % of the tamp density. In comparison to the sampling point, that gains 41.3 % packing density, this packing density reached only 79.7 % of the tamp density. In summary, the optimized parameter is 6.4 % closer to the theoretical optimum.

Responsible for this effect could be a correlation between the adhesion of the powder on the roller and the realized powder compaction. In front of the coating system there exist two areas of powder fluid. The first area is thrown in front of and the second area is cached by the coating mechanism and will be used for the compression. The lower the compression area is, the higher is the adhesion of the roller on the powder. In case of a blade its shape influences the different areas in front. But with a contra rotating roller, the rotating speed has a high influence on the flow properties. In this case the contra rotating speed is the parameter, which regulates by the adhesion of the used material the compression. In figure 10 the correlation between the resulting speed and the packing density of polyamide 12 is approximately shown as the blue line. The red line shows the tamped density of PA 2200 and it can be seen as the maximum gainable value of the packing density in a laser sintering process. The graph shows three zones: The instable, the optimized and the lower zone of packing density as a function of the resulting speed. In the first zone, the resulting speed of the roller is too low and causes instable processing. Because of the high compression of the powder, the inside parts of the build container moved and the surface of the powder layer shows cracks because of the induced forces. In the second zone, the optimized packing density could be reached. The ratio of compressing and the sliding powder at the front allows a solid process with a high packing density. In the third zone, the rotation is too fast, so the roller throws too much powder in front of it. Because of this effect, there is not enough powder in the zone of compression and as a result the packing density decreases.

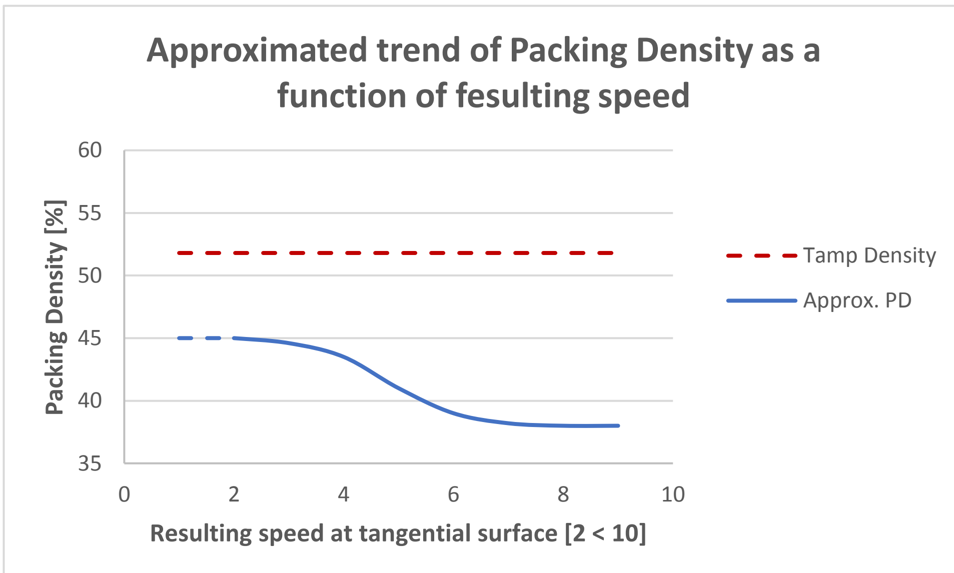


Figure 10: Packing Density of PA 2200 as a function of resulting tangential speed

As illustrated in table 1, the described effect of this correlation strongly depends on the used material. Due to this, the approximated graph might look different for other materials.

Conclusion

An initial study of the influence of the ratio between the translation and the contra-rotating coating mechanism and the influence on the packing density was conducted. This study proved that high values of packing density could be reached by an adjustment of the ratio between translation and contra-rotating speeds. The ratio in laser sintering machines is not adjustable, so the potential higher packing densities cannot be reached. Due to this it also becomes clear that the rounded blade system gains a higher packing density than the dynamic coating system in the commercial system.

The results demonstrate a high influence of the ratio between translation and contra-rotating speed on the generated packing density. Further, the next studies should detect the coherences between the generated surface of additive build parts, the geometrical quality, and the influences of the stability of the laser sintering process. The essential experiments could use the translation speed as another parameter and find some solid parameters to build a job faster without any losses of the part quality. By using this knowledge, faster parameters could be found to reduce the non-productive time in the laser-sintering process.

Another possibility is to qualify new material systems. Due to the adjustable parameters of the dynamic coating system, many materials could be processed - something that a standard machine is not able to do. New blade shapes should be designed to serve the requirements of different material systems than polyamide 12. An easy way to check the suitability by visual control has been figured out and should be validated. The visual control of the surface could include the possibility of an in-line process controlling. By evaluating the structure of the powder bed surface, a robust process could be guaranteed to prevent aborted processes.

References

[1] Gebhardt, A.: Rapid Prototyping. Werkzeuge für die schnelle Produktentstehung. München [u.a.]: Hanser 2000

[2] Gebhardt, A.: Generative Fertigungsverfahren. Rapid prototyping - rapid tooling - rapid manufacturing. München: Hanser 2007

[3] Schmid, M.: Selektives Lasersintern (SLS) mit Kunststoffen. Technologie Prozesse und Werkstoffe. München: Hanser 2015

[4] Übernahme DTM durch 3DSystems, 3D Systems, 2001

[5] Niino, Toshiki and Sato, Kazuki: Effect of Powder Compaction in Plastic Laser Sintering Fabrication. SFFS - Proceeding (2009), S. 193–205

[6] Drexler, M.: Zum Laserstrahlschweißen von Polyamid 12 - Analyse zeitabhängiger Einflüsse in der Prozessführung. Technisch-wissenschaftlicher Bericht / Lehrstuhl für Kunststofftechnik, Universität Erlangen-Nürnberg, Bd. 73. 2016

[7] N.n.:Datenblatt ProX™ 500 SLS® 3D Produktionsdrucker

[8] Wohlers, T.: Wohlers Report 2015 - 3D printing and additive manufacturing state of the industry. Fort Collins, Col: Wohlers Associates 2009

[9] Hellerich, W., Harsch, G. u. Baur, E.: Werkstoff-Führer Kunststoffe. Eigenschaften, Prüfungen, Kennwerte. München: Hanser 2010

[10] Kaiser, W.: Kunststoffchemie für Ingenieure. Von der Synthese bis zur Anwendung. München: Hanser 2016

[11] Domininghaus, H., Elsner, P., Eyerer, P. u. Hirth, T.: Kunststoffe. Eigenschaften und Anwendungen. VDI-Buch. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg 2008

[12] Wegner, A.; Witt, G.: Anlagenabhängigkeit von optimalen Prozessparametereinstellungen beim Laser-Sintern unterschiedlicher Thermoplaste, In: Rapid.Tech – International Trade Show & Conference for Additive Manufacturing - Proceedings of the 13th Rapid.Tech Conference Erfurt, München, Carl Hanser Verlag, S. 90-106, 2016.

[13] Wegner, A. u. Witt, G.: Betrachtung zur Pulvernutzungsdauer beim Laser-Sintern und Einfluss der Prozessführung auf die Entstehung von Ausschussbauteilen. Rapidtech 2012. 2012