NOBEL PROCESS OF RECYCLING SELECTIVE LASER SINTERING POWDER FOR HIGH INJECTION MOLDING

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Abstract

[0001] The **SLS** process (**Selective Laser Sintering**) is an **Additive Manufacturing** (**AM**) process that uses a laser to sinter powdered material, typically nylon/polyamide material to produce physical parts layer by layer. With new techniques, appears new problems and challenges. One of the big challenges related to **Selective Laser Sintering** process is the residual thermoplastic powder that cannot be reused again in the new builds, **EOS** [1] recommends a refresh rate of 50% virgin powder mixed with 50% recycled powder to ensure enough part quality. [2].

[0002] A common solution is to reuse the unfused material in subsequent prints by refreshing the recycled feedstock with a percentage of virgin powder, but the remaining powder will not be used.

[0003] The potential of saving cost recycling powder is very substantial worldwide. EOS [1], is perhaps the largest SLS specialist on the market. In 2016, the company claimed to have around 3000 units installed worldwide, 51 per cent of which are SLS systems. [3]

[0004] With recycling background in mind, this doctorate thesis culminate in a **Nobel recycling process for the unfused powder material** and a “state of the art” **Apparatus for treatment of residual thermoplastic powder**, that convert the unused powder into granules to be easily used in High Injection Molding process, both (process and apparatus) are patented application filled by **Ford Motor Company** (inventor Bruno Alves) [4] and [5].

[0005] The **Nobel recycling process of residual thermoplastic powder** takes into consideration all physical properties of the material plastic used, **PA3200 GF** and performed extensive testing and reports.

[0006] The **Apparatus for treatment of residual thermoplastic powder** includes in one step of the process, the residual powder is provided and compressed into granules as raw material for a primary shaping process. A pressing apparatus with two roller elements rotating in opposite directions and having lateral surfaces adjacent to one another in a pressing area is used to compress the powder into the granules. The lateral surfaces each having a plurality of molding elements assigned to one another in pairs such that the powder is compressed into granules in the pressing area. A cam mechanism positioned within one of the roller elements and configured to deflect the plurality of molding elements radially as a function of an angle of rotation of the roller element can be included.

[0007] For study purposes, this doctorate thesis can help others (readers and fellow researchers) providing more information about **Additive Manufacturing (AM)** and **recycling possibilities**, saving cost for companies globally, Another **important focus** for this research is sustainability, protecting our planet from micro plastics and loss of resources.

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Materials and methods

[0008] For all research and testing was used Ford motor company (Ford-Werk GmbH) facilities, in Merkenich, Germany [6].

[0009] All documentation regarding additive manufacturing is based on supplier's information, website documentation and **Rapid Technology Center** (Ford) knowhow.

[0010] The approach for my research is based on 3 main questions:

- Is it possible to recycle the residual powder (old powder) that normally is going to waste after using the process selective laser sintering?
- How can we re-use this material?
- What process can we develop to take the best from the recycling process?

[0011] All tests were performed using **EOS P770 SLS** machines, material **PA3200GF**, and one injection molding machine **ENGEL 160**, all machines are available on **Rapid Technology Center** in Ford-Werke Gmbh, Merkenich.

[0012] Based in the fact that Ford machines follows standard test procedures, and machines are constantly calibrated to the European norms, I´m assuming with a very degree with certainty that all results here can be replicated in other facilities globally from others researchers and leaders in the field of SLS, Additive Manufacturing.

[0013] The thesis conclusion and results will help Ford and other companies working with selective laser sintering, reducing the costs, waste and looking for sustainable ways of recycling materials.

Contents and results

1. CHAPTER I

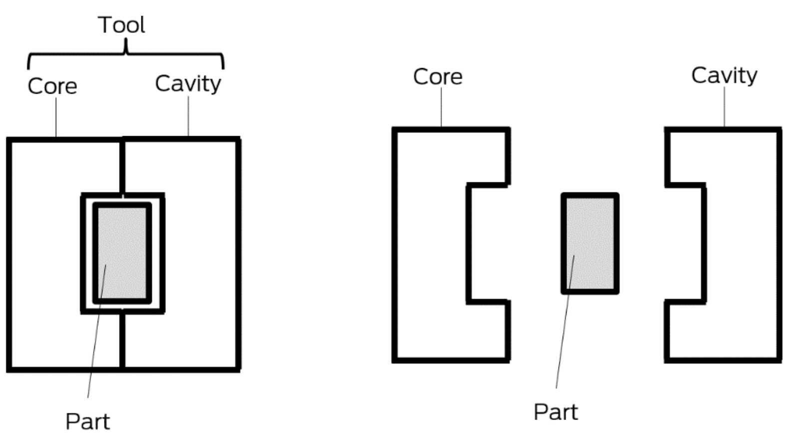
1.1. Introduction to Additive manufacturing for Polymers

[0014] Additive manufacturing (**AM**) or additive layer manufacturing (**ALM**) is the industrial production name for **3D printing**, a computer controlled process that creates three dimensional objects by depositing materials, usually in layers. [6]

[0015] **3d printing** is a complementation to the traditional manufacturing processes:

- **Formative manufacturing** (forms material into desired shape using a tool)

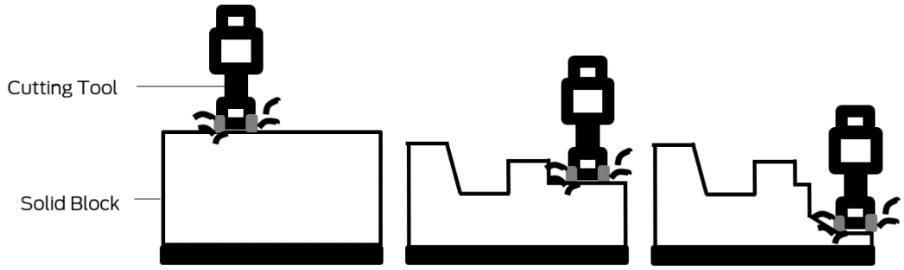
Figure 1 – Example of a tool (high injection tool)



High volume production of one design by using a mold (e.g. injection molding)

- **Subtractive manufacturing** (removes material from a solid block)

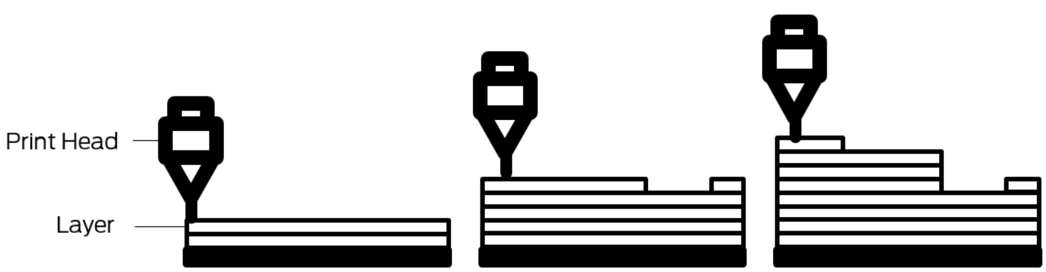
Figure 2 – Example of a part produced via direct milling



Low-mid volume production for simple geometries (e.g. milling of tools)

- **Additive manufacturing** (adds material to build up the solid model)

Figure 3 – Example of a part 3d printed



Low volume production for complex geometries (e.g. 3D printing)

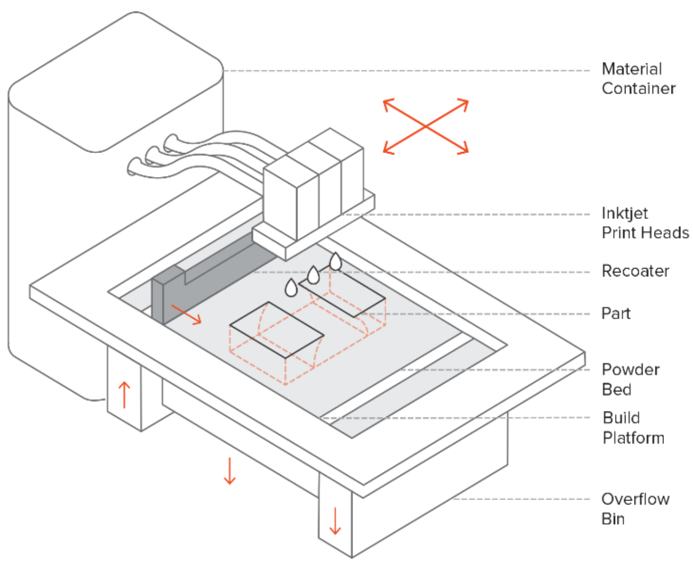
1.2. Additive Manufacturing Processes

[0016] There are number of distinct AM processes with their own standards, which include:

1.2.1. Power Bed Fusion

1.2.1.1. Multi Jet Fusion [MJF]

Figure 4 - Illustration of a Multi Jet Fusion machine which shows the name of parts (3Dhubs)



[0017] The **Multi Jet Fusion** process, or **MJF** process for short, is an additive manufacturing technique that was developed by **Hewlett-Packard** (HP) [7] and does not require a laser for printing. [8]

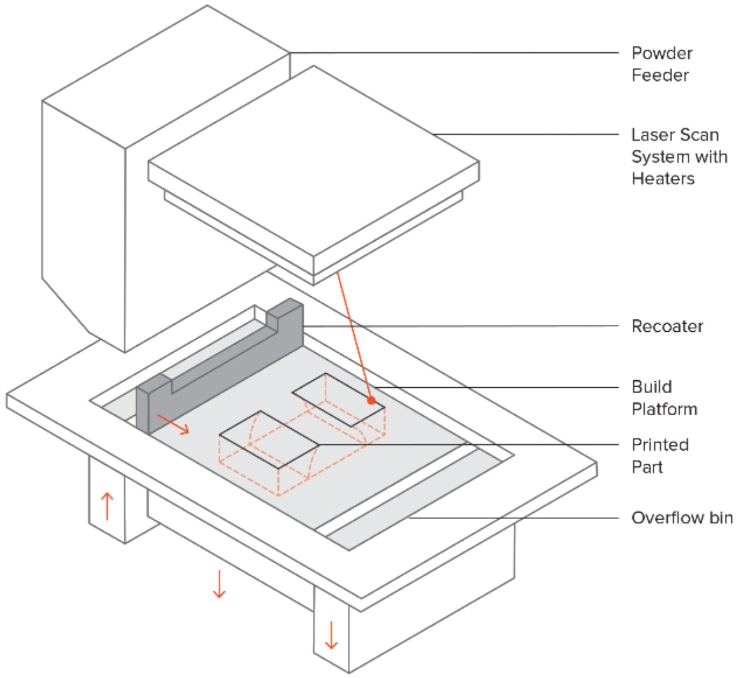
[0018] The technology here works on a powder basis. In a multi-step additive process, three-dimensional objects are printed with the help of so-called agents. A uniformly heated powder bed (typically 80 µm thick) is applied in layers to the build platform in the printer. In a second step, a heat-conducting liquid, the Fusion Agent, is selectively sprayed onto this powder base - depending on the digitally defined shape. To form the contour, a heat-retardant liquid, the detailing agent, is applied to the powder bed at the same time on the edge areas of the component. A lamp then heats the work area. The heat energy given off leads to physicochemical reactions between the powder and the two fusion agents. A solid material is created where the heat-conducting agent was sprayed onto the powder base. The three work steps are repeated until the object to be printed is finished. After printing, the object must be taken out of the kit and manually freed from excess powder and cleaned. [8]

[0019] The technology was developed by HP as an alternative to laser sintering, but in practice there are weaknesses in terms of quality and flexibility compared to selective laser sintering [8]

[0020] **Multi Jet Fusion** improved the powder waste significantly compared to Selective Laser sintering, it´s required only 25% virgin powder on new builds. [2]

1.2.1.2. Selective Laser Sintering [SLS]

Figure 5 - Illustration of a Selective Laser Sintering Machine which shows the name of parts (3Dhubs)



[0021] **Selective laser sintering** (SLS) is an additive manufacturing (AM) technique that uses a **laser** as the power source to sinter powdered material (typically nylon or polyamide), [9]

[0022] **SLS** 3D printing has been a popular choice for engineers in product development for decades. Low cost per part, high productivity, and established materials make the technology ideal for a range of applications from rapid prototyping to small batch or bridge manufacturing. [9]

[0023] Recent advances in machinery, materials, and software have made SLS printing accessible to a wider range of businesses, enabling more and more companies to use tools previously limited to a few high-tech industries. [9]

1.2.1.2.1. Selective Laser Sintering [SLS]- How the process works?

1. Powder is dispersed in a thin layer on top of a platform inside of the build chamber.
2. The printer preheats the powder to a temperature just below the melting point of the raw material. This makes it easier for the laser beam to raise the temperature of specific regions of the powder bed as it traces the model to solidify a part.
3. The laser scans a cross-section of the 3D model, heating the powder to just below or right at the melting point of the material. This fuses the particles together mechanically to create one solid part. The unfused powder supports the part during printing and eliminates the need for dedicated support structures.
4. The build platform lowers by one layer into the build chamber, typically between **50 to 200 microns**, and a recoater applies a new layer of powder material on top. The laser then scans the next cross-section of the build.
5. This process repeats for each layer until parts are complete, and the finished parts are left to cool down gradually inside the printer.
6. Once parts have cooled, the operator removes the build chamber from the printer and transfers it to a cleaning station, separating the printed parts and cleaning of the excess powder.

1.2.1.2.2. Part Recovery and Post-processing:

[0024] Selective laser sintering post-processing requires minimal time and labor and leads to consistent results for batches of many parts.

[0025] After a print job is complete, the finished parts need to be removed from the build chamber, separated, and cleaned of excess powder. This process is typically completed manually at a cleaning station using compressed air or a media blaster.

[0026] SLS parts have a slightly rough, grainy surface finish right out of the printer similar to a medium grit sandpaper. Nylon provides a range possibility for post-processing, such as tumbling, dyeing, painting, stove enameling, metal coating, bonding, powder coating, and flocking. [10]

1.2.1.2.3. Recovery and Post-processing:

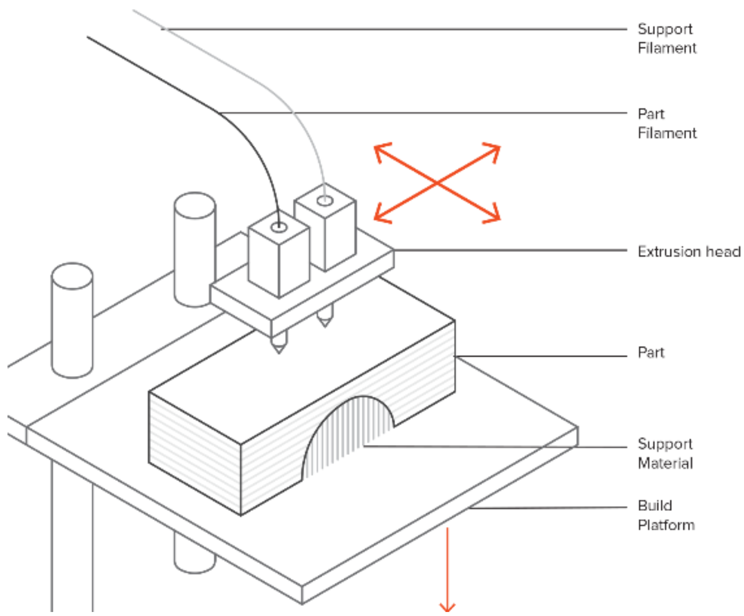
[0027] Any excess powder remaining after part recovery is filtered to remove larger particles and can be recycled. Unfused powder degrades slightly with exposure to high temperatures, so it should be refreshed with new material for subsequent print jobs. This is the main reason why this doctorate thesis mainly focusses in a Nobel recycling process for the unfused powder material.

[0028] This ability to re-use material for subsequent jobs makes SLS one of the least wasteful additive manufacturing methods, nevertheless follow this research we can conclude that the cost and waste still very important to consider.

1.2.2. Material Extrusion

1.2.2.1. Fused Deposition Modeling [FDM]

Figure 6 - Illustration of a Fused deposition modeling Machine which shows the name of parts (3Dhubs)



[0029] **Fused deposition modeling** (FDM), also known under the trademarked term **Fused Filament Fabrication** (FFF), sometimes also called **Filament Freeform Fabrication**, is a 3D printing process that uses a continuous filament of a thermoplastic material. [11] Filament is fed from a large spool through a moving, heated printer extruder head, and is deposited on the growing part.

[0030] The print head moves under computer control to define the printed part shape. Usually the head moves in two dimensions to deposit the material thermoplastic and in one horizontal plane, or layer, at a time. After the layer is printed, the build platform then moved vertically by a small amount to begin a new layer.

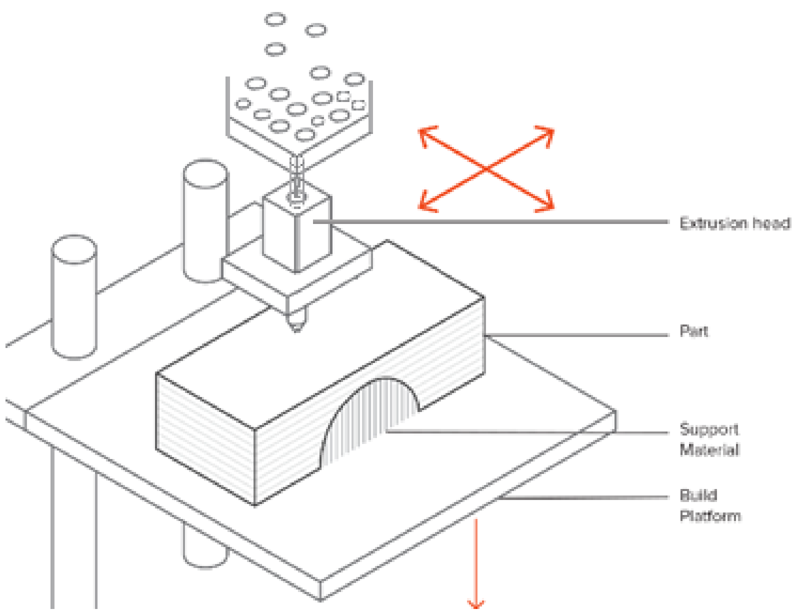
[0031] The speed of the extruder head may also be controlled to stop and start deposition and form an interrupted plane without stringing or dribbling between sections.

[0032] The 3D printer FDM is a part of the material extrusion additive manufacturing processes responsible for raw material melting and forming it into a continuous profile. A wide variety of filament materials are extruded, including thermoplastics such as acrylonitrile butadiene styrene (ABS), [12] polylactic acid (PLA), high-impact polystyrene (HIPS), thermoplastic polyurethane (TPU) and aliphatic polyamides (nylon).

[0033] **Fused deposition modeling** (FDM), is now the most popular process (by number of machines) for hobbyist-grade 3D printing. [13] Other techniques such as photopolymerization and powder sintering may offer better results, but they are much more costly.

1.2.2.2. *Arburg Plastic Freeforming [APF]*

Figure 7 - Illustration of an Arburg Plastic Freeforming Machine which shows the name of parts (3Dhubs)



[0034] The Freeformer is a machine that can manufacture fully functional plastic parts using Arburg's proprietary additive manufacturing technology, called Arburg Plastic Freeforming. [14] The machine can produce soft and hard plastic pieces individually or in small-volume orders. The unit can produce plastics without the need for a mold by relying upon the company's AKF technology.

[0035] Arburg's AKF technology is different from standard AM technologies because it **melts standard granulates** identical to the **injection molding process**, this feature is very important for the **NOBEL PROCESS OF RECYCLING SELECTIVE LASER SINTERING POWDER** thesis, because we can use the recycling material instead of using expensive specialty materials. The technology also uses axis, instead of support structures, to hold the object upright during the production process, allowing for more freedom of design.

[0036] The Freeformer machine has the capacity to build virtually any plastic object by strategically building the item layer-by-layer, drop-by-drop. The discharge unit secretes minuscule droplets of the melted granulates while the axis moves, allowing for "freeform" manufacturing. The entire production process also occurs automatically.

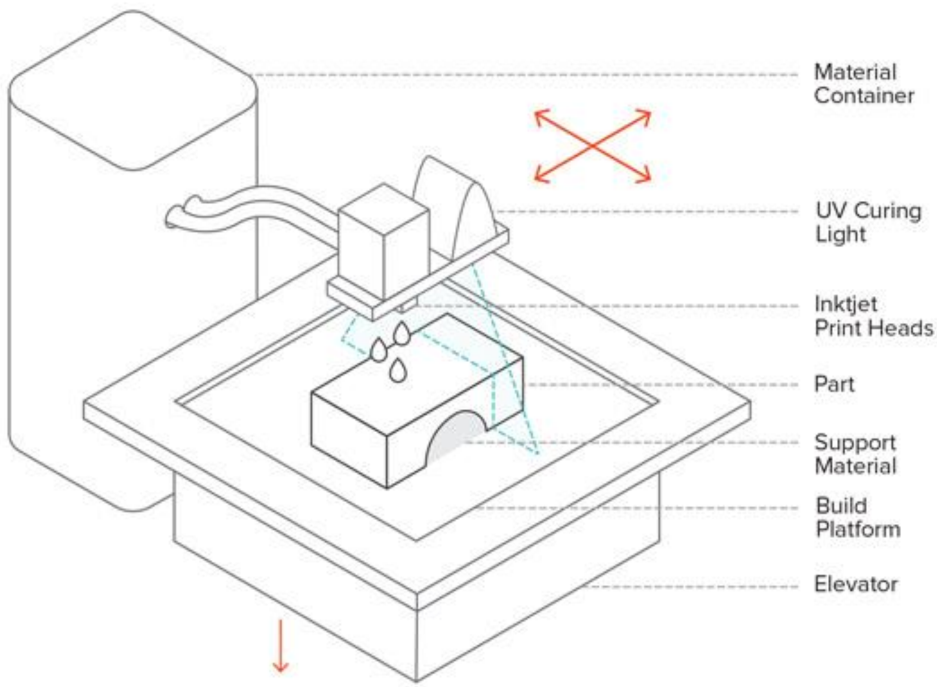
[0037] The Freeformer is based upon the use of 3D CAD file technology, which enables the machine to directly read engineering instructions and build the desired object automatically. The injection nozzle also uses piezo technology to accurately build items drop-by-drop.

[0038] While the new machine allows for increased capabilities, the Freeformer also keeps production costs low, as standard granulates are low-cost production materials that produce high-quality products. The new technology also allows for the manufacturing and production of complex 3D geometric items, including items that combine hard and soft plastic, as the machine produces products "freeform." [14]

1.2.3. Material Jetting

1.2.3.1. *Material Jetting [MJ]*

Figure 8 - Illustration of a Material Jetting Machine which shows the name of parts (3Dhubs)



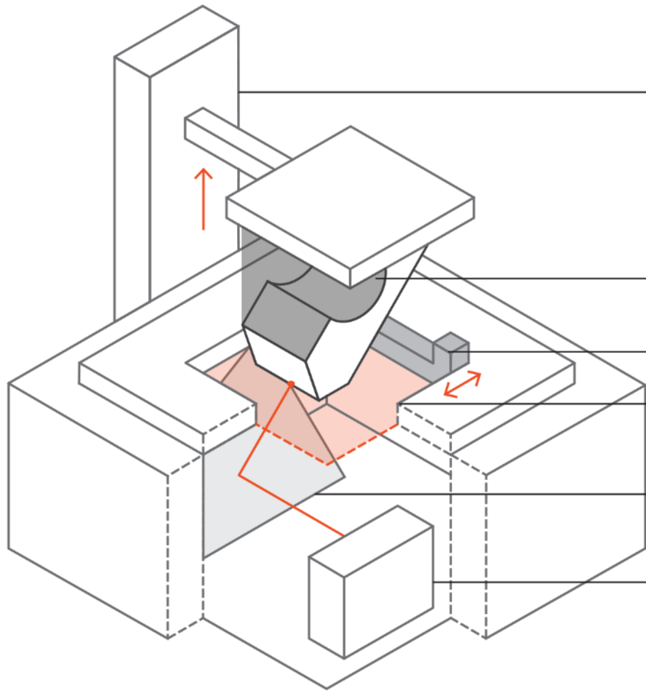
[0039] **Material Jetting (MJ)** is an additive manufacturing process that operates in a similar fashion to 2D printers. In material jetting, a printhead (like the printheads used for standard inkjet printing) dispenses droplets of a photosensitive material that solidifies under **ultraviolet (UV)** light, building a part layer-by-layer. The materials used in MJ are thermoset photopolymers (acrylics) that come in a liquid form.

[0040] **Material Jetting (MJ)** creates parts of high dimensional accuracy with a very smooth surface finish. Multi-material printing and a wide range of materials (such as ABS-like, rubber-like and fully transparent materials) are available in Material Jetting. These characteristics make MJ a very attractive option for both visual prototypes and tooling manufacturing. Nevertheless, material jetting has some key limitations that we present in this article.

[0041] A variation of the MJ process uses Drop-On-Demand (DOD) printheads to dispense viscous liquids and create wax-like parts. DOD is used almost exclusively for manufacturing investment casting patterns though and for this reason we will not discuss it here further. [15]

1.2.4. Vat Photopolymerization

1.2.4.1. Stereo Lithography [SLA]



[0042] **Stereo Lithography (SLA)** is an additive manufacturing process that belongs to the **Vat Photopolymerization** family. In SLA, an object is created by selectively curing a polymer resin layer-by-layer using an ultraviolet (UV) laser beam. The materials used in SLA are photosensitive thermoset polymers that come in a liquid form.

[0043] **SLA** is famous for being the first 3D Printing technology: its inventor patented the technology back in 1986. [16] If parts of very high accuracy or smooth surface finish are needed, SLA is the most cost-effective 3D printing technology available. Best results are achieved when the designer takes advantage of the benefits and limitations of the manufacturing process.

[0044] SLA has many common characteristics with Direct Light Processing (DLP), another Vat Photopolymerization 3D printing technology. For simplicity, the two technologies can be treated as equals.

2. CHAPTER 2

2.1. Selective Laser Sintering - Powder

Figure 9 – SLS powder, material PA3200 GF

[0045] The Ph.D thesis: Additive Manufacturing- Nobel process of recycling selective Laser Sintering powder for High Injection Molding is focus mainly on recycling **Nylon materials**, but can be process can be used also for other materials.

[0046] Nylon materials, for example **PA 3200 GF** is a whitish, glass-filled polyamide 12 powder, which is characterized by an excellent stiffness in combination with good elongation at break. Laser-sintered parts made from PA 3200 GF possess excellent material properties [17]:

- High stiffness
- High mechanical wear-resistance
- Good thermal loadability
- Excellent surface quality
- High dimensional accuracy and detail resolution
- Good processability
- excellent long-term constant behavior

[0047] A typical application for **PA 3200 GF** is the usage e.g. for final parts within the engine area of cars, for deep-drawing dies or any other application which requires stiffness, high heat distortion temperature and low abrasive wear.

Mechanical Properties	Value	Unit	Test Standard
Izod Impact notched (23°C)	**4.2**	kJ/m2	ISO 180/1A
Izod Impact unnotched (23°C)	**21**	kJ/m2	ISO 180/1U
Shore D hardness (15s)	**80**	-	ISO 868
Ball indentation hardness	**98**	MPa	ISO 2039-1

[0048] The properties of parts manufactured using additive manufacturing technology (e.g. laser sintering, stereolithography, Fused Deposition Modelling, 3D printing) are, due to their layer-by-layer production, to some extent direction dependent. This must be considered when designing the part and defining the build orientation.

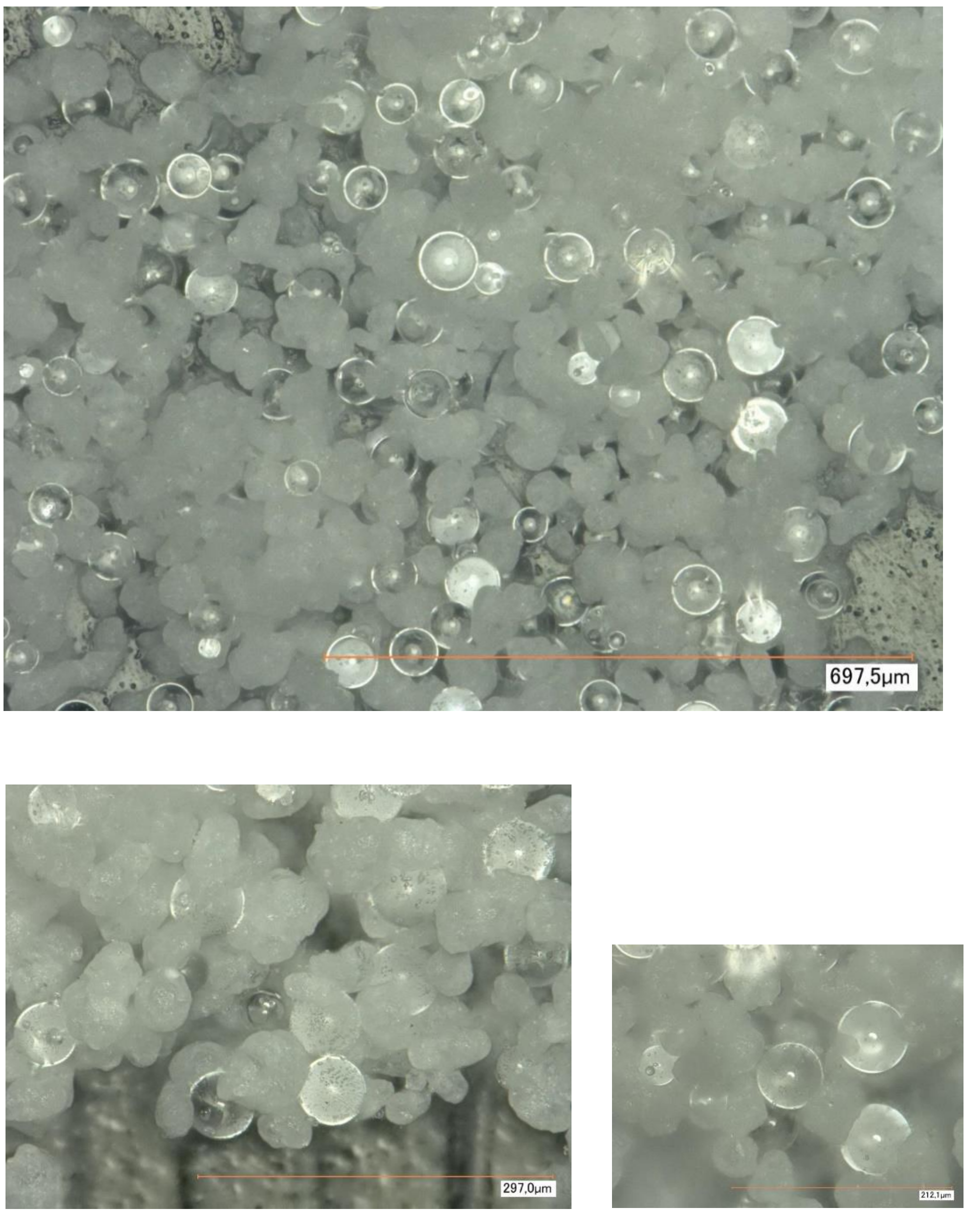
3D Data	Value	Unit	Test Standard
Tensile Modulus (X Direction)	**3200**	MPa	ISO 527-1/-2
Tensile Modulus (Y Direction)	**3200**	MPa	ISO 527-1/-2
Tensile Modulus (Z Direction)	**2500**	MPa	ISO 527-1/-2
Tensile Strength (X Direction)	**51**	MPa	ISO 527-1/-2
Tensile Strength (Y Direction)	**51**	MPa	ISO 527-1/-2
Tensile Strength (Z Direction)	**47**	MPa	ISO 527-1/-2
Strain at break (X Direction)	**9**	%	ISO 527-1/-2
Strain at break (Y Direction)	**9**	%	ISO 527-1/-2
Strain at break (Z Direction)	**5.5**	%	ISO 527-1/-2
Charpy impact strength (+23°C, X Direction)	**35**	kJ/m2	ISO 179/1eU
Charpy notched impact strength (+23°C, X Direction)	**5.4**	kJ/m2	ISO 179/1eA
Flexural Modulus (23°C, X Direction)	**2900**	MPa	ISO 178
Flexural Strength (X Direction)	**73**	MPa	ISO 178
Temp. of deflection under load (1.80 MPa, X Direction)	**96**	°C	ISO 75-1/-2
Temp. of deflection under load (0.45 MPa, X Direction)	**157**	°C	ISO 75-1/-2

Thermal Properties	Value	Unit	Test Standard
Melting temperature (10°C/min)	**176**	°C	ISO 11357-1/-3
Vicat softening temperature (50°C/h 10N)	**179**	°C	ISO 306
Vicat softening temperature (50°C/h 50N)	**166**	°C	ISO 306

Other Properties	Value	Unit	Test Standard
Density (lasersintered)	**1220**	kg/m³	EOS Method

[0049] The **PA 3200 GF** powder material is delivered in white color. The **glass-filled** (small glass spheres) in polyamide 12 powder can be easily seen (figure 10)

Figure 10- Selective laser Sintering powder PA3200 GF (font: Ford Motor Company)



3. CHAPTER 3

3.1. SLS Powder ratios

[0050] A critical issue relating to the quality of Nylon SLS is the powder ratio used. The material for commercial Nylon SLS prints is a blend of new and recycled **PA 3200 GF** or **PA2200/other** powder.

[0051] To achieve the best part quality and material performance, **EOS** recommend a powder ratio of 1:1 for **PA2200** . [18] This ratio can of course be adjusted, and given the price of the Nylon powder, it can be tempting to begin adjusting this ratio to make it stretch further and increase margins. This decision will **have a major effect** on the quality of the parts. If the ratio is stretched, the parts will not be quite as white, and they will lose a lot of tensile strength. Accuracy will also be reduced and the ability to dye the parts consistently will be lost.

[0052] Because of all these factors, the powder ratio is kept at range **50% new powder (virgin) + 50% old powder for PA2200** and/or **70% new powder (virgin) + 30% old powder for PA 3200 GF**. To keep ratios consistent, is used mixing units that simultaneously mixes and transports the powder directly to the machines.

[0053] With this ratio we can extrapolate how much powder will be lost and cost, depending the quantity of machines/builds. Following example using:

- **EOS P770** machine (construction volume: **700 x 380 x 580 mm**) [19]
- **PA 3200 GF** material (ratio 70/30) [17]
- **PA 3200 GF** price per kg= 47,90 € [20]

Box Dimension	Volume	Density	Full ht	New material Weight (ratio70/30)
0,7 x 0,38 x 0,58 m	**0,15428** m³	**1220** kg/m³	188,2 Kg	131,75 Kg

Cost new material per Build/Job: 131,75 Kg x 47,90 € = ~6310 €

Cost old material per Build/Job: 56,45 Kg x 47,90 € = ~2703 €

Builds	Ratio	New Powder	Old powder	Stock Current Old Powder	Stock Old Powder After Print	Cost powder/lost
1	**70/30**	188,2 Kg	0 Kg	0 Kg	188,2 Kg	9014,78 €
5	**70/30**	131,75 Kg	56,45 Kg	527 Kg	715,2 Kg	34258,08 €
10	**70/30**	131,75 Kg	56,45 Kg	1185,75 Kg	1373,95 Kg	65812,205 €
20	**70/30**	131,75 Kg	56,45 Kg	2503,25 Kg	2691,45 Kg	**128920,455 €**

[0054] With the above table the costs and quantity of old powder that will be scraped is very substantial, for 20 builds a company is losing **~128920 €** in old powder.

[0055] The main question about the old powder is how to recycle it, and to take the maximum value from it. We saw previously that the amount of old powder is increasing for each build, leading to an increasing in stock.

[0056] The best application for the old powder is to re-use it in **High Injection Process**, further with this thesis we can see the test results, and why **High injection Molding** should be the process to consider. The main issue is that High injection machines are not prepared to work fine powder. This thesis shows also how to solve this issue with the patent disclosures: **102019203285.0** (**METHOD FOR THE TREATMENT OF RESIDUAL THERMOPLASTIC POWDERS**) and **102019203284.2** (**APPARATUS FOR TREATMENT OF RESIDUAL THERMOPLASTIC POWDER**).

4. CHAPTER 4

4.1. High Injection Molding

[0057] The Injection molding is a manufacturing process used for mass production, the high injection process produce parts by injecting molten material (normally thermoplastic or/and thermosetting polymers) into a mold,

[0058] Material **granulate/pellets** are fed into a heated barrel, mixed (using a helical shaped screw), and injected into a mold cavity producing the part, where it cools and hardens to the configuration of the cavity. [21] [22]

[0059] After a product is designed, usually by an industrial designer or an engineer, molds are made by a toolmaker from metal, usually either steel or aluminium, and precision-machined to form the features of the desired part. Injection moulding is widely used for manufacturing a variety of parts, from the smallest components to entire body panels of cars.

[0060] Advances in 3D printing technology, using photopolymers that do not melt during the injection moulding of some lower temperature thermoplastics, can be also used for some simple injection molds and prototypes.

[0061] Parts to be injection moulded must be very carefully designed to facilitate the moulding process; the material used for the part, the desired shape and features of the part, the material of the mold, and the properties of the molding machine must all be taken into account. The versatility of injection moulding is facilitated by this breadth of design considerations and possibilities.

5. CHAPTER 5

5.1. SLS Powder in high Injection

[0062] To use the old powder from Selective Laser sintering process in high injection molding process was required to perform tensile mechanical test to check the quality of the injected parts. Was used a High injection Mold to produce the standard Tensile test specimen **ISO8256 type 3**.

Figure 11 ISO8256 type 3

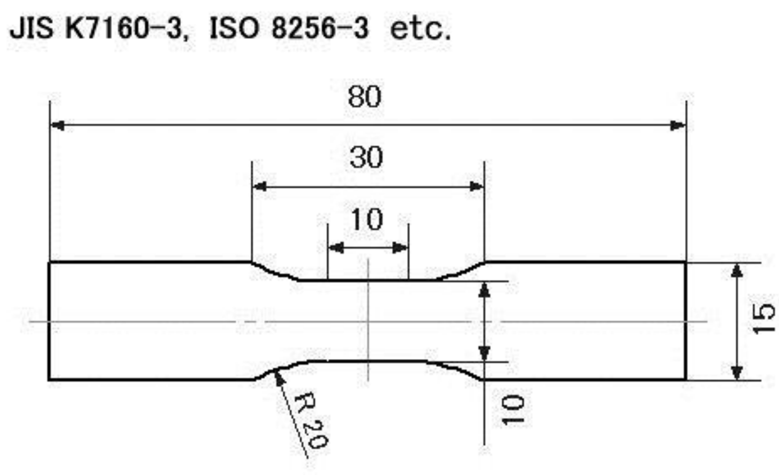
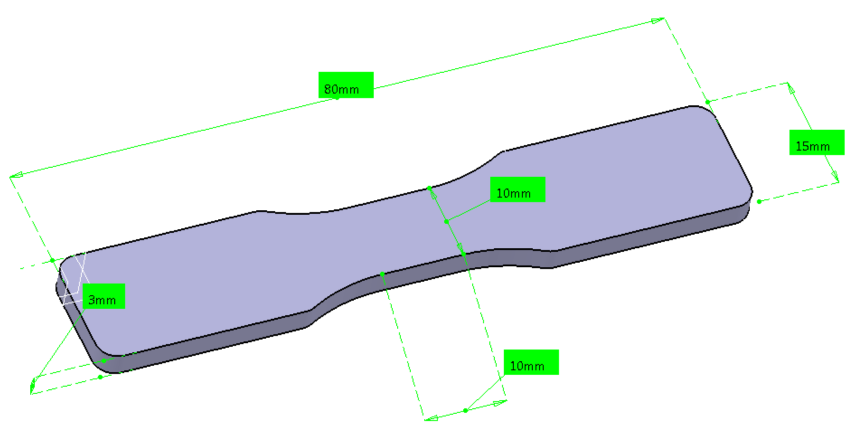


Figure 12 Standard Tensile Test Specimen (3D data)



[0063] First tests were performed using standard material: **AUROmid® PA6** from **Aurora** [23] in an **Engel Victory160** injection molding machine [24], the reason to choose this nylon material was to give us the result of a “standard” PA6 material, in a way that we can then compare with the results using “old” SLS powder.

[0064] 8 test specimens were measure tensile strength and elongation, at Ford Motor Company, below test **ISO8256 type 3** report table:

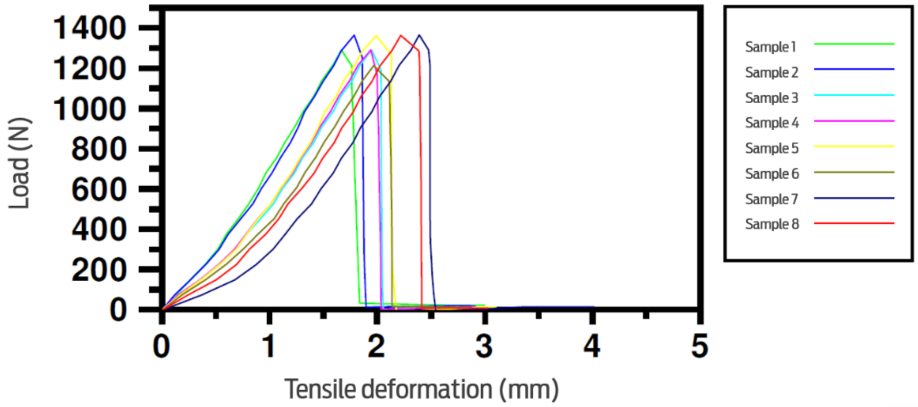
	Max Load (N)	**Elongation at Break (mm)**
1	1971,10	132,26
2	1977,70	136,71
3	1909,90	114,20
4	1575,19	53,98
5	1972,09	148,93
6	1965,56	157,17
7	1945,64	143,39
8	1940,94	154,22
Average	**1907,27**	**130,11**
Minimum	1575,19	53,98
Maximum	1977,70	157,17

[0065] Second step was to produce the tensile test specimens **ISO8256 type 3** using **“new” (virgin) and “old” PA3200 GF SLS power**. The idea is to determinate and identify if the **“old”** material has different mechanical properties compared to the original **“new”** material.

[0066] Tensile test parameters:

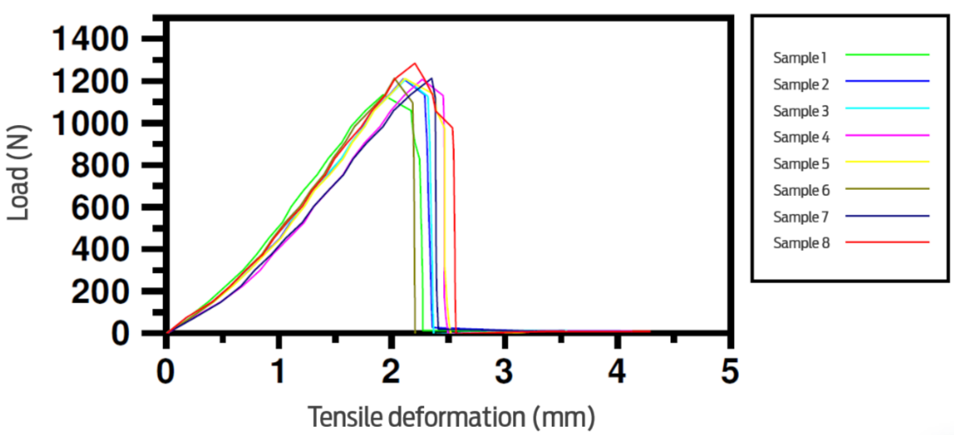
- Speed 50,00 mm/min
- Room temperature: 21°

Figure 13 - ***New SLS PA3200 GF powder***



	Max Load (N)	Elongation at Break (mm)
1	1290,22	3,00
2	1363,87	2,91
3	1290,13	2,75
4	1291,05	2,85
5	1360,74	3,11
6	1212,74	2,88
7	1365,48	4,01
8	1363,04	3,03
Average	**1317,16**	**3,07**
Minimum	1212,74	2,75
Maximum	1365,48	4,01

Figure 14 - ***"OLD" SLS PA3200 GF powder***



	Max Load (N)	Elongation at Break (mm)
1	1134,48	3,51
2	1209,22	4,13
3	1209,04	3,55
4	1207,85	3,51
5	1211,50	3,26
6	1212,07	3,05
7	1211,93	3,53
8	1283,89	4,29
Average	**1210,00**	**3,60**
Minimum	1134,48	3,05
Maximum	1283,89	4,29

[0067] The tensile test results shows that the "new" and "old" powder have very similar results, was expected that the samples using the "new" (virgin) powder have higher load results, mainly because the SLS process will expose the powder to 170°-180°C some hours, during the build phase, which could result that the powder lose slightly mechanic properties.

[0068] Very interesting result is that the samples using the "old" powder have in average better elongation results.

[0069] From tensile tests the conclusion is that using "old" powder in high injection molding is an excellent approach to recycling the powder, behaves very similar like virgin PA3200GF material, no significant losses in mechanical properties were observed.

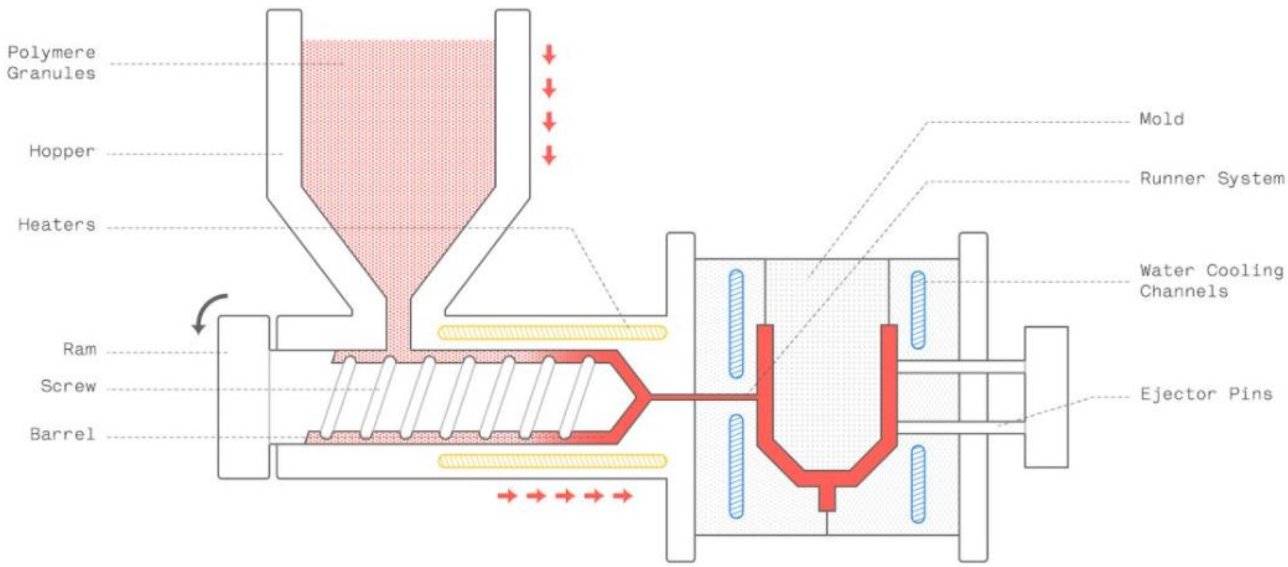
[0070] The big challenges to use this powder in High Injection process is that the injection machines are not prepared to work fine powder, rather with granulate material. This leads to several issues detected:

- **The powder material gets stuck inside the Hopper** (figure 15)
- **Exterior contamination with powder,** the injection machines are not completely sealed for such a small particle

- **The machine operators are not willing to work with fine powders instead of granulate material**

Injection Unit (High injection machine scheme)

Figure 15 - ***Injection Unit - (source: www.3dhubs.com)***



[0071] The conclusion is that is required to convert that “old” powder to granulate, so can be used globally in every single high injection facility, without the need to convert or change anything in the “standard” injection machines.

[0072] To convert powder into granulate pellets, there are several option on the market, but all of them need to melt the powder to produce the pellets, which will have a very significant impact in the material properties and energy required for this process. Each time that the material is melted and cooled down with contact with water or other, will decrease mechanical proprieties, and increasing recycling cost.

[0073] The solution is to develop a new system, that will convert the powder into pellets without melting and cooling the material, using pressure.

[0074] The apparatus will press the powder into pellets, converting the material without losing mechanical properties.

[0075] Two patents disclosure were recorded using this research in recycling residual thermoplastic powder.

Patent disclosure

Nobel recycling process for the unfused powder material with an apparatus for treatment of residual thermoplastic powder

102019203285.0 (METHOD FOR THE TREATMENT OF RESIDUAL THERMOPLASTIC POWDERS)

102019203284.2 (APPARATUS FOR TREATMENT OF RESIDUAL THERMOPLASTIC POWDER)

1. Cross-reference to related applications

[0076] This application claims priority to and the benefit of German Patent **Application No. 102019203285.0** and **Application No. 102019203284.2** filed on March 11, from the inventor Bruno Alves. The disclosure of the above application is incorporated herein by reference.

2. Field

[0077] The present disclosure relates to treatment of residual plastic powder and particularly to treatment of residual plastic powder.

3. Background

[0078] The statements in this section merely provide background information related to the present disclosure and may not constitute prior art.

[0079] Various processes currently exist by means of which, based on design data, three-dimensional models can be produced from shapeless or shape-neutral materials such as powders (possibly with the addition of a binder) or liquids (sometimes also including molten solids). These processes are also known under collective terms such as “rapid prototyping,” “rapid manufacturing” or “rapid tooling.” In this case, a primary shaping step is often carried out, in which the starting material is either present in liquid form from the outset or is liquefied in the meantime and cures at an intended location. One known process in this case is fused deposition modeling (FDM), in which a workpiece is built up in layers from thermoplastic material. The plastics material is fed for example in the form of a powder or a strand, is melted and applied in molten form by a print head, which successively applies individual, generally horizontal, layers of the object to be produced.

[0080] Also known are processes in which a pulverulent material, for example a plastics material, is applied in layers and selectively cured by means of a locally applied or printed-on binder. In yet other processes, for example **selective laser sintering (SLS),** a powder is applied in layers, for example using a doctor blade, to a base plate. The powder is selectively heated by means of suitable focused radiation, for example a laser beam, and as a result sintered. After a layer has been built up, the base plate is lowered slightly, and a new layer is applied. In addition to plastics materials, it is also possible to use ceramics or metals as the powder. The non-sintered powder is removed after the production process. In a similar process, selective laser melting (SLM), the amount of energy introduced by the radiation is so high that the powder is regionally melted and solidifies into a coherent solid body. This process is used particularly in the case of metal powders.

[0081] In the powder-based processes, issues arise regarding further use of the **residual powder that is not part of the finished object**. Said powder can sometimes be reused in the additive manufacturing process, as long as its chemical and physical properties have not changed or have changed only to an insignificant extent. However, it is possible, for example in SLS, for powder particles that have been exposed to increased temperatures in the vicinity of the laser beam without actually being sintered to have altered properties that make them unfit for direct reuse. Even partial sintering of powder particles makes them unsuitable for reuse, since it is not possible to build up smooth powder layers therewith.

[0082] In principle, such residual powders could be used for example in plastics processing. However, for this purpose, it would first of all be necessary to convert them into a granular form, to which end the powder would be melted and cooled down again for example with water. This is **energy- and cost-intensive**, however, and the melting impairs the material properties of the plastics material. Furthermore, when cooling down with water, moisture collects or accumulates in the granules, likewise impairing the properties thereof.

[0083] **US 1,299,570 A** discloses a tableting machine having a head that is rotatable about a vertical axis of rotation and has an upper punch and a lower punch cooperating therewith, which are formed in a vertically displaceable manner. In one region, rollers are arranged above and below the head, which deflect the punches toward one another during the rotation of the head. In the process, material located between the punches is pressed into a tablet form. Upon further rotation of the head, first of all the upper punch and then the lower punch is lifted, with the result that the tablet is ejected. A similar machine is known from **US 2006/0013914 A1**, although this machine has two pairs of rollers for two successive pressing operations. **US 4,833,880 A** also discloses a comparable apparatus.

[0084] **US 5,236,603 A** discloses a plant for recycling plastics containers. Therein, in different treatment steps, first of all the plastics containers are cut up to the size of flakes, lightweight materials are separated out by way of an air current, the plastics pieces are washed and dried multiple times, and residues are separated from the plastics pieces by means of two hydrocyclones. In addition to plastics milk bottles, it is also possible to recycle for example agricultural films or medical waste.

[0085] **US 4,452,733 A** discloses a device for the treatment of liquid radioactive waste. Said device has a unit for drying the radioactive waste, a unit for grinding the dried radioactive waste, and a press-molding machine for molding the ground radioactive waste by means of press rollers, the lateral surfaces of which each have pockets. In order to make it easier for air to escape during press-molding, vent grooves adjacent to the pockets are formed in the lateral surface.

[0086] **US 2004/0012114 A1** discloses a process for producing a granular intermediate produce from at least one substantially pulverulent or particulate thermoplastic or thermoelastic polymer and substantially inert fillers. The intermediate product is intended to be processed further into plastics moldings by way of thermoplastic processing methods. In that case, the polymer and the fillers are mixed, and the powder mixture is compacted to form granules with a relatively large grain size, wherein the compacting takes place without plastification of the polymer exclusively under mechanical pressure.

[0087] **EP 2,915,652 A1** discloses a method for producing a masterbatch. In that case, a powder is prepared as raw material, which exhibits residual toner. The powder is fed to a vented twin-screw extruder, melted and extruded, with the result that an extrudate is formed. The extrudate is subsequently chopped up into pellets.

[0088] Considering the above indicated references, there is still room for improvement in the utilization of residual powder that arises in additive manufacturing processes such as selective laser sintering, for example. In particular, it would be desirable to utilize the residual powder that cannot be used again in the additive manufacturing process.

4. Summary

[0089] This section provides a general summary of the disclosure and is not a comprehensive disclosure of its full scope or all of its features.

[0090] It should be noted that the features and measures specified individually in the following description can be combined with one another in any desired technically meaningful way and disclose further forms of the present disclosure. The description additionally characterizes and specifies the present disclosure, in particular in conjunction with the figures.

[0091] An apparatus for the treatment of residual thermoplastic powder (also referred to herein simply as “residual powder”) from an additive manufacturing process is provided. The additive manufacturing process, in which the residual powder arises, can be selective laser sintering (SLS). In some variations of the present disclosure, the residual powder is at least partially thermoplastic, i.e. it exhibits at least one thermoplastic material, optionally also a mix or mixture of thermoplastic materials. In particular polyamides are suitable as such materials. In addition, it is also possible for further, non-thermoplastic materials to be contained. Different grain sizes of the powder may be provided. In at least one variation, the grain size is less than 0.1 mm. If powder particles are agglomerated in the course of the additive manufacturing process, for example by partial sintering, the agglomerates in question can also have larger dimensions.

[0092] The apparatus comprises a feed apparatus for feeding powder, which includes the residual powder, to a pressing area. Such a feed apparatus can have one or more dispensing openings from which the powder emerges for example under gravity and drops or trickles into the pressing area. In this case, the feed apparatus is arranged at least partially vertically above the pressing area. In addition, other ways of introducing the powder into the pressing area, for example spraying, are included. However, gravity-supported feeding can be the simplest and most energy-efficient option. The powder includes the residual powder, i.e., it may optionally include at least one further component, which can be likewise present in powder form.

[0093] The apparatus includes two rotatable roller elements, which are drivable in opposite directions. Lateral surfaces of the two rotatable roller elements are adjacent to one another in a pressing area and each laterally have a plurality of molding elements that are assigned to one another in pairs in order to compress powder into granules in the pressing area. Each of the roller elements (which are referred to in the following text as a first and a second roller element) is rotatable about a respective axis of rotation. The axes of rotation can extend generally parallel to one another but can also extend for example at an angle of up to 45° or up to 30° to one another. In some variations of the present disclosure the axes of rotation extend horizontally, that is to say at an angle of 90° to the acting direction of gravity. In other variations the axes of rotation do not extend horizontally. In such variations the axes of rotation can be inclined at less than 30° to the horizontal plane. The roller elements are rotatable, i.e., mounted in a rotatable manner, and drivable in opposite directions. Thus, they are drivable by at least one drive such that they rotate in opposite directions to one another. For example, in some variations of the present disclosure a drive with an equal rotational speed is provided, such that the roller elements rotate in opposite directions synchronously with one another. Also, the roller elements are configured such that their lateral surfaces move downward in the pressing area, with the result that the powder is conveyed downward between the roller elements in the pressing area such that a continuous downward movement of the powder occurs when the feed apparatus allows the powder to drop into the pressing area.

[0094] As regards the drive, there are various possibilities. For example, each roller element may be drivable by a separate motor drive. A motor drive may act on one of the roller elements, which in turn drives the other roller element, or both roller elements may be coupled to a motor drive by force-transmitting and/or transmission elements.

[0095] The lateral surfaces, that is to say the external surfaces of the two roller elements with respect to the particular axis of rotation, are arranged adjacently to one another in a pressing area. As used herein the term or phrase “pressing area” refers to an area in which the lateral surfaces of the roller elements are at the smallest distance from one another. The term “roller element” should not be interpreted as being limiting.

Although a roller- or roll-like shape of the roller elements is desired, wherein the lateral surface is designed to be entirely or partially rotationally symmetric with respect to the particular axis of rotation, this does not have to be the case.

[0096] Each of the roller elements has a plurality of molding elements laterally positioned (i.e., in the region of the lateral surface). The molding elements are normally distributed around the circumference of the lateral surface, wherein they may typically be offset and in particular spaced apart from one another. The molding elements of each roller element can be formed so as to be identical to or different than one another. The molding elements of the two roller elements are assigned to one another in pairs in order to compress powder into granules in the pressing area. In other words, in each case a first molding element of the first roller element is assigned to a second molding element of the second roller element. The positions of these two molding elements and the rotary movements of the roller elements are coordinated with one another such that the molding elements are located opposite one another in the pressing area, such that a molding cavity for the granules to be produced is formed between the molding elements in the pressing area, the powder being compressed into granules in said molding cavity. As will be discussed further below, the cavity can also be partially formed by additional parts of the apparatus. The molding elements in this case at least partially define the shape of the granules to be produced. In each case two molding elements can be configured to mold exactly one grain of the granules or to mold a plurality of grains. The compressing of the powder results at least partially from the fact that the mutually assigned molding elements approach one another (i.e., move towards each other) when they move toward the pressing area, in which the roller elements are arranged adjacently to one another.

[0097] Granules are understood in this connection to be a granular material, wherein the shape of the individual grains is not defined. They can be designed for example in a spherical, cylindrical, polygonal or amorphous manner. The size of the grains of the granules is not defined in this connection either. In some variations of the present disclosure, a largest dimension of the grains is between 0.5 mm and 10 mm. Both the shape and the size of the individual grains of the granules can be uniform or nonuniform. Each of the grains of the granules includes at least partially of a thermoplastic material, optionally also of a mixture of thermoplastic materials, since it is manufactured by compressing the powder.

[0098] In at least one variation of the present disclosure, no melting or fusion of the thermoplastic powder takes place during compression. The cohesion of an individual grain of the granules can in this case be based for example on a microscopic form fit between individual powder particles or on intermolecular forces between the surfaces of adjacent powder particles. Depending on the speed and intensity of the compression, considerable heating up of the powder can result, although in some variations the melting temperature of the powder is not exceeded. In some variations, there is no active heating of the powder, that is to say no heating by heating elements provided for this purpose occurs. In order to inhibit undesirably great heating up of the powder, parts of the apparatus, in particular the molding elements, can be manufactured from a material with good thermal conductivity, for example a metal.

[0099] The (at least partially thermoplastic) granules that are producible with the apparatus can be usable in particular as raw material for primary shaping processes in plastics processing, such as injection molding, transfer molding, extrusion, blow molding or the like.

[00100] In one form of the present disclosure a cam mechanism is included and configured to deflect the molding elements of a first roller element radially depending on (as a function of) the angle of rotation of the first roller element. In other words, while the molding elements of the first roller element move during the rotation of the first roller element, they are deflected radially (with respect to the first axis of rotation) by the cam mechanism, specifically depending on the angle of rotation of the first roller element. For example, a particular radial deflection of the particular molding element corresponds to a particular angle of rotation. The term “cam mechanism” should not be interpreted as being limiting here. The cam mechanism can be designed in particular such that the described deflection results from the rotary movement of the first roller element by force diversion. That is, during the rotary movement, the molding elements are carried along, and during this guided movement, a force diversion takes place, which brings about the radial deflection. In general, the cam mechanism provides the molding elements move on a path of movement that is not concentric with respect to the first axis of rotation. Depending on the configuration of the cam mechanism, the path of movement can also be noncircular. The molding elements are in this case arranged preferably on a guide frame which is stationary in a radial direction and with respect to which they are radially deflectable. The guide frame on which the lateral surface of the first roller element can also be at least partially formed carries the molding elements along in a tangential direction, while allowing them to move in a radial direction. In particular, the molding elements can be guided on the guide frame in a radially displaceable manner. The roller elements including the molding elements and the cam mechanism form parts of a pressing apparatus.

[00101] In variations where the first axis of rotation extends horizontally or at an angle of less than 30° to the horizontal, the molding elements move downward within the pressing area and following the latter. In this case, a dispensing area can be arranged indirectly or directly beneath the pressing area with respect to the vertical. In the dispensing area, which is arranged downstream of the pressing area with respect to the rotary movement, the finished granules are dispensed, with the result that the first molding elements become free for the next pressing operation. The finished granules can drop downward under gravity and be collected there. Overall, the movement of the powder and of the finished granules within the apparatus can thus be brought about at least partially by gravity, and this can contribute to simplifying the structure and possibly toward a saving of energy.

[00102] As a result of the apparatus according to the teachings of the present disclosure, it is possible to process at least partially thermoplastic powder, which may include in particular a residual powder that arises during an additive manufacturing process, into granules which can subsequently be used for primary shaping processes such as injection molding, among others. In many cases, the powder, which arises as a residual powder for example during selective laser sintering, can be processed in the apparatus without additives. The production of the granules takes place in this case without substantial heating up and in particular without melting of the thermoplastic material. Accordingly, no cooling of a melt for example using water is necessary, with the result that undesired collection of liquid in the granules does not occur. As will become more apparent in view of the present disclosure, the apparatus can be configured in a comparatively simple and compact manner.

[00103] The compression of the powder takes place at least partially on account of the rotary movement of the two roller elements, by which the molding elements are guided toward one another. By way of the cam mechanism provided according to the teachings of the present disclosure, various steps in the manufacture of the granules can be controlled in an enhanced manner compared with molding elements that are mounted in a fixed position with respect to the roller element. There are various possibilities here, some of which will be explained in the following text.

[00104] In some variations of the present disclosure, the cam mechanism is configured to deflect the molding elements of the first roller element radially outward in the pressing area in order to support the compression of the powder. In other words, when the molding elements of the first roller element move toward the pressing area during the rotation of the first roller element, they are deflected radially outward by the cam mechanism. The deflection supports the compression of the powder, since the mutual approaching of the cooperating molding elements, which occurs anyway on account of the rotary movement of the roller elements, is enhanced when the (first) molding elements of the first roller element are deflected radially outward in the pressing area. As a result, the distance between the cooperating molding elements can be reduced, the mutual approaching thereof can be accelerated and/or a pressure acting on the powder can be increased.

[00105] In at least one variation of the present disclosure, the lateral surfaces of the two roller elements can also be spaced apart from one another in the pressing area. In this case, there is a gap between the lateral surfaces such that more powder can trickle or fall through between the roller elements. In other variations, the lateral surfaces are configured to roll in contact with one another in the pressing area. In other words, the lateral surfaces bear at least partially against one another in the pressing area and roll in contact with one another during the rotary movement of the two roller elements. The lateral surfaces do not in this case have to be formed in a smooth or rotationally symmetric manner but can also have a meshing structure. As a result, one roller element can drive the other roller element.

[00106] According to one form of the present disclosure, the cam mechanism has a cam element that is off-center with respect to a first axis of rotation of the first roller element and is arranged within the first roller element, the molding elements being radially deflectable by said cam element. The cam element is formed or arranged in an off-center manner with respect to the first axis of rotation, i.e. in particular an outer surface, facing the molding elements, of the cam element is formed in an off-center manner. Thus, if the molding elements move in a tangential direction following the rotary movement of the first roller element, they are guided along the outer surface of the cam element, wherein, by force diversion, a radial deflection can take place, for example when the molding elements approach the pressing area.

[00107] While the cam element is off-center with respect to the first axis of rotation, it can be formed in a rotationally symmetric manner with respect to a cam axis that is offset with respect to the first axis of rotation. Therefore, it is also formed concentrically with this cam axis. For example, the cam element can be formed in a wheel-like or roller-like manner, wherein the cam axis forms the axis of symmetry thereof.

[00108] In particular, the cam element can in this case be rotatable about the cam axis synchronously with the first roller element. In other words, the cam element rotates in the same direction and at the same angular velocity within the first roller element.

[00109] In some variations of the present disclosure, the first roller element has guide channels that extend radially inward with respect to the lateral surface thereof. In such variation the molding elements can be guided within said guide channels and said guide channels can be configured to receive powder upon reaching the pressing area. The guide channels can be formed for example within the abovementioned guide frame.

The guide channels can extend radially inward, wherein they can extend in particular, although not necessarily, parallel to the radial direction. The cross section of the guide channels can be adapted in particular to a cross section of the respective molding element, such that the molding element bears in a flush manner within the guide channel. In addition to guiding the respective molding elements, the guide channels also serve to receive powder when the portion of the first roller element having the particular guide channel passes into the pressing area. This design is advantageous in particular when the two lateral surfaces of the roller elements roll in contact with one another, such that there is no gap between the roller elements in the pressing area. In this case, the guide channel forms as it were a receiving area for powder.

[00110] In some variations of the present disclosure the apparatus is configured to form the granules at least partially within the guide channels. In such variations, each particular guide channel can form a part of the abovementioned molding cavity for molding the granules. For example, the cavity can be bounded radially on the inside by the molding element of the first roller element and radially on the outside by the corresponding molding element of the second roller element, while there is bounding by the guide channel transversely to the radial direction, i.e. tangentially-axially. As a result of the outward radial deflection according to the teachings of the present disclosure of the molding element, the powder that is located in the meantime entirely or partially within the guide channel is compressed.

[00111] In at least one variation, the cam mechanism is configured to deflect the molding elements radially outward after leaving the pressing area, in order to eject granules from the guide channels. “After leaving the pressing area” refers to the portion of the movement of a particular molding element in which it moves out of the pressing area.

In addition, “after leaving the pressing area” can be the part of the rotary movement that (indirectly or directly) follows the passage through the pressing area. If, as described above, an outward radial deflection takes place within the pressing area, this can be continued after the pressing area has been left. During the rotary movement, the distance between the first molding elements and the second molding elements increases after the pressing area has been left, such that the granules are no longer enclosed between the first and second molding elements. To some extent, the granules can drop out of the guide channels during the further rotary movement under their own weight. Under certain circumstances, however, as a result of the pressing operation, they stick to the guide channel. The corresponding adhesion can be overcome when the molding element moves (further) radially outward, as described. As a result, the granules are pushed out of or ejected from the guide channel.

[00112] It should be understood that it can be difficult to compress all of the powder that is fed to the pressing area by the feed apparatus entirely into granules. In other words, powder arises that, in contrast to granules, cannot be used in conventional processes in plastics processing but could be used in a further pressing operation. Advantageously, the apparatus has, beneath the roller elements, a separating apparatus, which is designed to collect granules and powder and to separate them from one another. The separation can take place in different ways, wherein the separating apparatus can have in particular a screen that can optionally be coupled to a drive that sets the screen in vibration. Where it is a matter of separating granules and powder here, this separation may not be complete, wherein for example small amounts of powder can remain stuck to the granules. This is generally irrelevant for a subsequent use of the granules, however.

[00113] Furthermore, the apparatus may advantageously have a return device, which is designed to return powder separated from the granules by the separating apparatus to a storage container of the feed apparatus. The return device can have different parts or portions that are based on different conveying principles. For example, the powder can be guided on conveyor belts. In particular, the powder can be guided within corresponding lines by an air current. In other words, an air current is generated, which carries along the powder. For example, a negative pressure can be generated by the storage container of the feed apparatus, the powder being drawn in by said negative pressure.

[00114] Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

5. Drawings

*Figure 16 - **Process scheme**- block diagram*

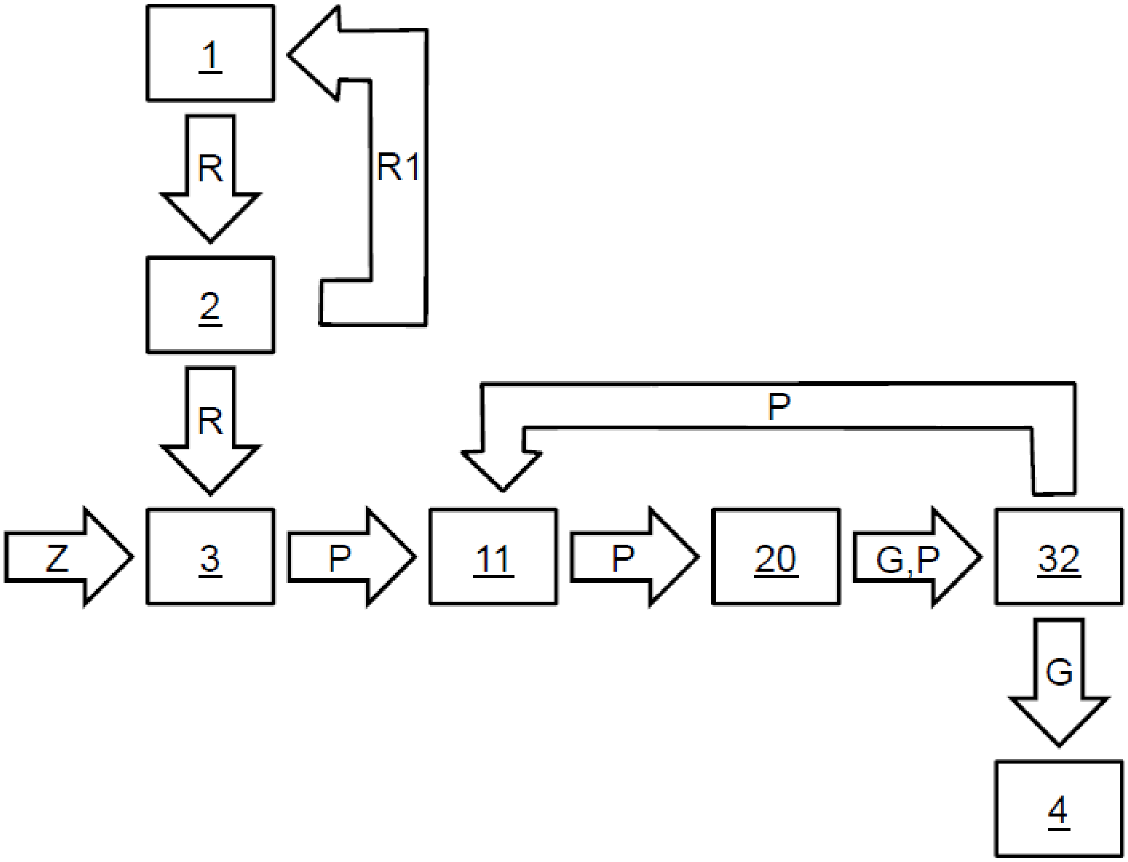


*Figure 17 - **schematic illustration - Apparatus to convert residual thermoplastic powder into granulate/pellets***

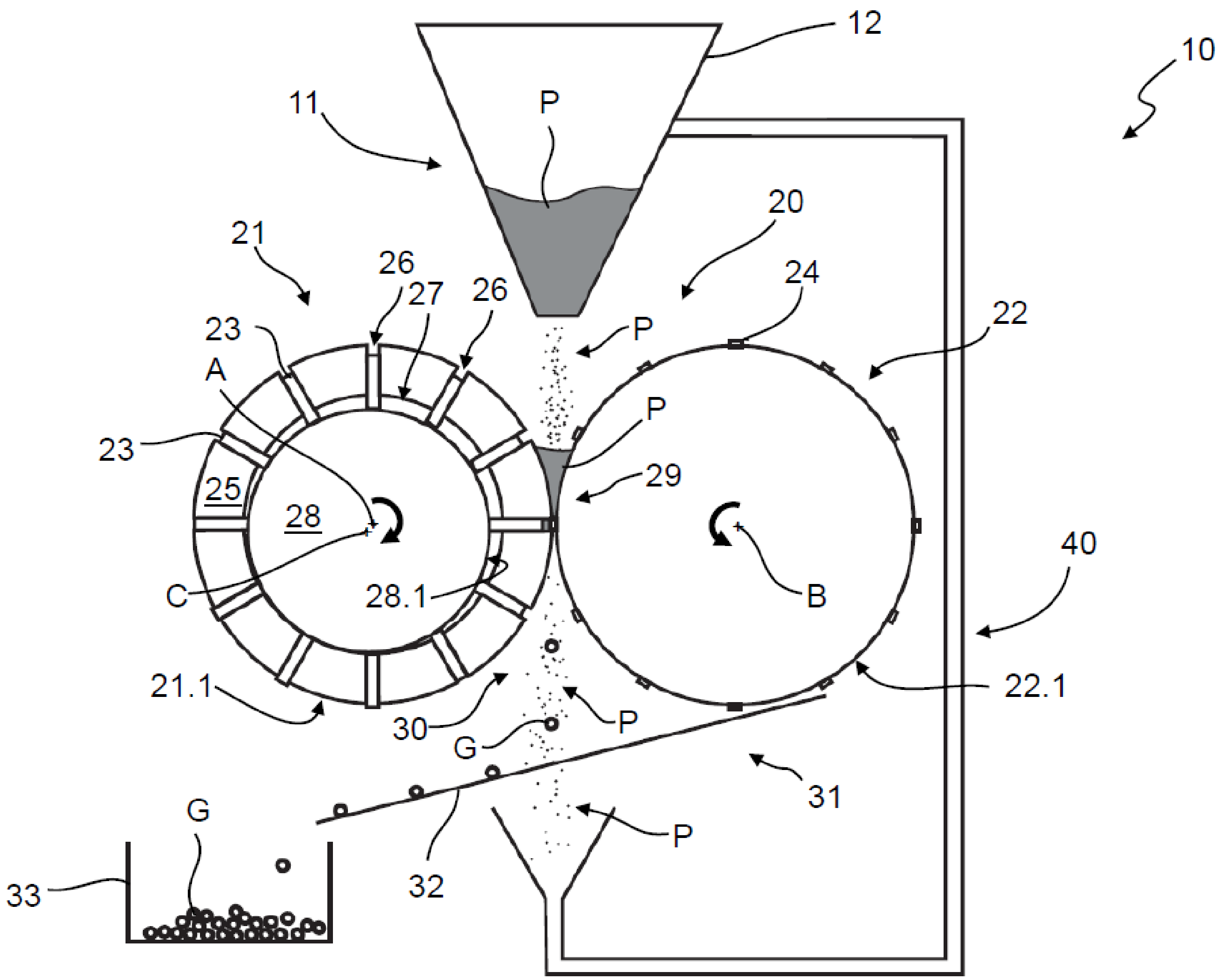
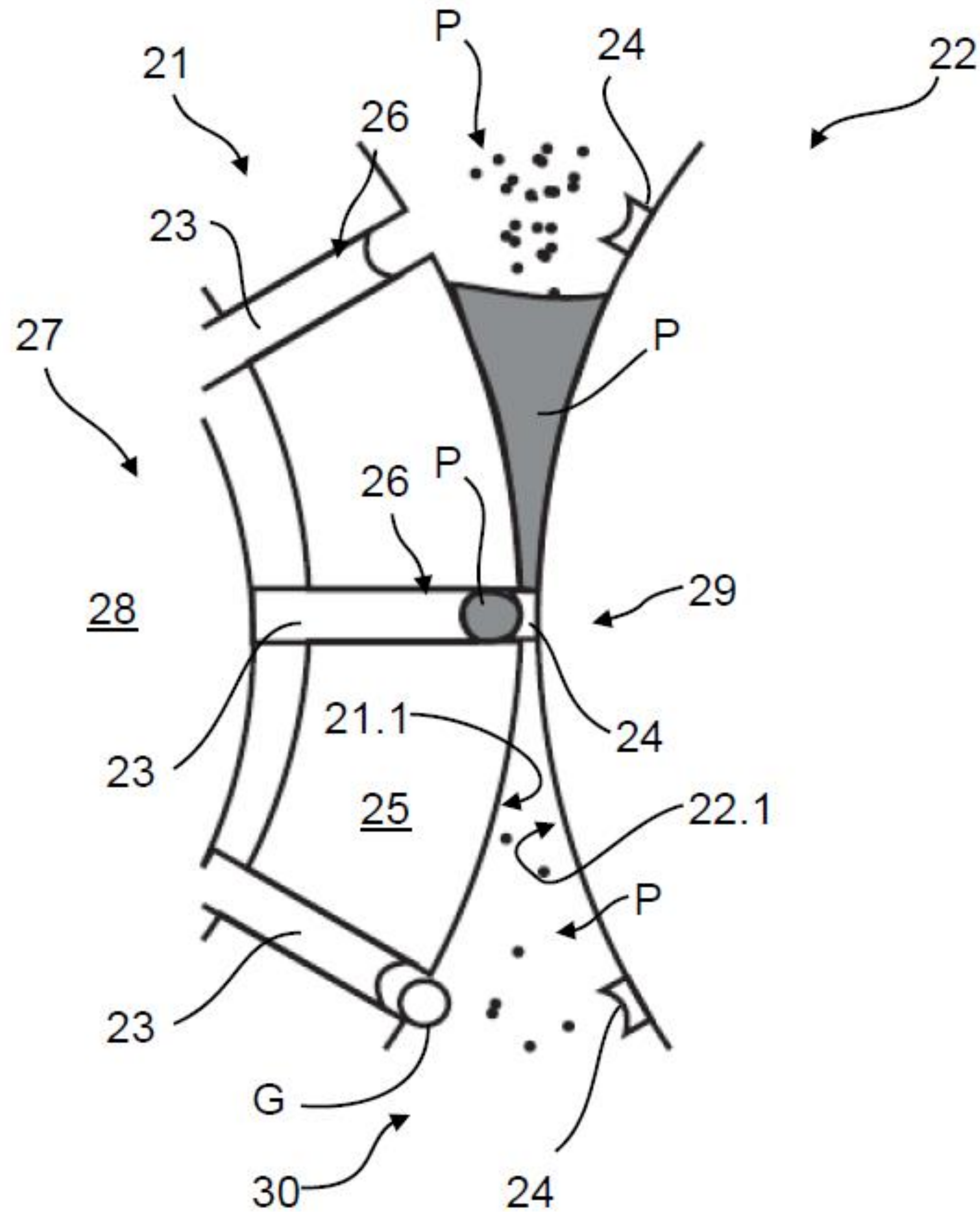


Figure 18 ***– Detail - Apparatus to convert residual thermoplastic powder into granulate/pellets***



[00115] In order that the disclosure may be well understood, there will now be described various forms thereof, given by way of example, reference being made to the accompanying drawings, in which:

[00116] **Figure 1** shows a block diagram of a process in which the apparatus according to the teachings of the present disclosure can be used;

[00117] **Figure 2** shows a schematic illustration of an apparatus according to the teachings of the present disclosure; and

[00118] **Figure 3** shows an enlarged detail view of **Figure 2**.

[00119] In the different figures, identical parts are provided with the same reference signs, for which reason these parts are generally described only once. Also, the drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

6. Detailed description

[00120] The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features.

[00121] **Figure 1** shows a block diagram of a process in which an apparatus 10 shown in **Figure 2** is used according to the teachings of the present disclosure. For example, a workpiece (not shown) is manufactured by selective laser sintering (SLS) in an SLS plant 1. To this end, a thermoplastic powder is used, which may be for example a polyamide filled with glass fibers. Residual powder R that remains after manufacture of the workpiece is fed to a first screen 2, where a share R1 of the residual powder R is separated off, returned and reused in the SLS plant 1. This first separating operation is optional.

[00122] Residual powder R that is not reused is fed, together with at least one additive Z (for example additional thermoplastic powder, a pigment, a filler or the like), to a mixer 3, where a powder P is mixed. This process step is likewise optional, and the powder P subsequently used can also consist exclusively of residual powder R. Otherwise, the powder P can have for example a weight proportion of at least 95% residual powder R, although other weight proportions are also possible. The powder P is filled into a storage container 12 of a feed apparatus 11, which is part of the apparatus 10 according to the present disclosure. The feed apparatus 11 is arranged above a pressing apparatus 20, which has a first roller element 21 and a second roller element 22. The roller elements 21, 22 are rotatable about a first and second axis of rotation A, B, respectively, which extend horizontally and parallel to one another. A drive (not shown) provides synchronous rotation in opposite directions. The feed apparatus 11 feeds the powder P to a pressing area 29 by allowing it to trickle or fall into the pressing area 29 under gravity.

[00123] Lateral surfaces 21.1, 22.1 (**Figure 3**) of the roller elements 21, 22, respectively, roll in contact with one another in the pressing area 29. The two roller elements 21, 22 have a plurality of molding elements 23, 24, respectively, in the region of their lateral surfaces 21.1, 22.1 (**Figure 3**). First molding elements 23 of the first roller element 21 are accommodated in a guide frame 25, within which they are displaceable radially with respect to the first axis of rotation A. Each first molding element 23 is in this case arranged in a radially extending guide channel 26 within the guide frame 25, the cross section of which is coordinated or dimensioned complimentary with the cross section of the molding element 23. The guide frame 25 also forms the first lateral surface 21.1 (**Figure 3**) of the first roller element 21. In at least one variation of the present disclosure, each first molding element 23 is assigned to a corresponding second molding element 24 of the second roller element 22 and cooperates therewith in the pressing area 29 in order to compress powder P into granules G. The second molding elements 24 are arranged in a fixed position on the second roller element 22 in at least one form of the present disclosure and project radially somewhat beyond the second lateral surface 22.1 (Figure 3) of the second roller element 22.

[00124] Arranged within the first roller element 21 is a roller-like cam element 28, which is formed or positioned off-center with respect to the first axis of rotation A but in a rotationally symmetric manner with respect to a cam axis C parallel to the first axis of rotation A. The cam element 28, which belongs to a cam mechanism 27, cooperates with the first molding elements 23 and deflects the first molding elements 23 radially depending on the angle of rotation of the first roller element 21. For example, the first molding elements 21 can be preloaded radially inward for example by spring elements (not shown) such that during their movement, the first molding elements follow the external contour 28.1 (**Figure 3**) of the cam element 28. Before and upon reaching the pressing area 29, each particular first molding element 23 is retracted into the guide channel 26.

[00125] As shown in Figure 3, the guide channel 26 in the process also receives powder P. During the further rotary movement of the roller elements 21, 22, the respectively assigned second molding element 24 engages in the guide channel 26 and thus closes the guide channel 26 toward or from the outside. The powder P contained in the guide channel 26 is compressed into granules G between the first molding element 23 and the second molding element 24, wherein the pressure required for this purpose is applied both by the mutual approaching of the molding elements 23, 24 in accordance with the rotary movement of the roller elements 21, 22 and by the fact that the first molding element 23 is deflected radially outward by the cam element 28 in the pressing area 29. The compression takes place without active heating up of the powder P. If heating of the powder P occurs as a side effect of friction and compression, the heating is minor and the powder P and in particular the residual powder R contained therein does not melt.

[00126] After leaving (i.e., rotating past) the pressing area 29, the first and second molding elements 23, 24 move apart, with the result that the granules G are released. In some variations of the present disclosure, the granules G are released from the guide channel 26 and drop out under gravity during the further rotation of the first roller element 21. In at least one variation, the first molding elements 23 are deflected further radially outward by the cam element 28 after the pressing area 29 has been left, with the result that the first molding elements 23 eject the granules G in a dispensing area 30. Returning to **Figure 2**, the granules G drop downward together with non-compressed powder P under gravity to a separating apparatus 31, which has a second screen 32 in the example illustrated. The grains of the granules G are retained by the screen 32 and, on account of the inclined position of the screen 32, pass into a container 33, while the particles of the powder P fall through the screen 32. The powder P can be guided back to the storage container 12 by a return apparatus 40 and are compressed subsequently into granules G. The return apparatus 40 is illustrated only schematically here and can have for example a system of pipes in which the powder P is sucked to the storage container 12 by a negative pressure.

[00127] The finished granules G can subsequently be used as raw material for various primary shaping processes in plastics processing. In the example in Figure 1, they are used in an injection-molding apparatus 4.

7. List of reference signs:

1	SLS plant
2, 32	Screen
3	Mixer
4	Injection-molding apparatus
10	Apparatus
11	Feed apparatus
12	Storage container
20	Pressing apparatus
21, 22	Roller element
21.1, 22.1	Lateral surfaces
23, 24	Molding element
25	Guide frame
26	Guide channel
27	Cam mechanism
28	Cam element
28.1	External contour
29	Pressing area
30	Dispensing area

31	Separating apparatus
33	Container
40	Return apparatus
A, B	Axis of rotation
C	Cam axis
G	Granules
P	Powder
R	Residual powder
R1	Share
Z	Additive

[00128] Unless otherwise expressly indicated herein, all numerical values indicating mechanical/thermal properties, compositional percentages, dimensions and/or tolerances, or other characteristics are to be understood as modified by the word “about” or "approximately" in describing the scope of the present disclosure. This modification is desired for various reasons including industrial practice, material, manufacturing, and assembly tolerances, and testing capability.

[00129] Although the terms first, second, third, etc. may be used to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections, should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer and/or section, from another element, component, region, layer and/or section. Terms such as “first,” “second,” and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section, could be termed a second element, component, region, layer or section without departing from the teachings of the example forms. Furthermore, an element, component, region, layer or section may be termed a “second” element, component, region, layer or section, without the need for an element, component, region, layer or section termed a “first” element, component, region, layer or section.

[00130] Spatially relative terms, such as “inner,” “outer,” “beneath,” “below,” “lower,” “above,” “upper,” and the like, may be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” the other elements or features. Thus, the example term “below” can encompass both an orientation of above or below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[00131] As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using a non-exclusive logical OR, and should not be construed to mean “at least one of A, at least one of B, and at least one of C.”

[00132] The description of the disclosure is merely exemplary in nature and, thus, variations that do not depart from the substance of the disclosure are intended to be within the scope of the disclosure. Such variations are not to be regarded as a departure from the spirit and scope of the disclosure.

8. Claims

What is claimed is:

1. An apparatus for treatment of a residual thermoplastic powder from an

additive manufacturing process, the apparatus comprising:

a feed apparatus for feeding powder to a pressing area, wherein the powder includes the residual thermoplastic powder;

two rotatable roller elements, wherein the two rotatable roller elements are drivable in opposite directions and each of the two rotatable roller elements have a lateral surface, the lateral surfaces are adjacent to one another in the pressing area, and each of the lateral surfaces has a plurality of moulding elements assigned to one another in pairs such that the powder is compressed into granules by the plurality of moulding elements in the pressing area; and

a cam mechanism configured to deflect the plurality of moulding elements of one of the two rotatable roller elements radially as a function of an angle of rotation of the one of the two rotatable roller elements.

2. The apparatus according to claim 1, wherein the cam mechanism is configured to deflect the moulding elements of the one of the two rotatable roller elements radially outward in the pressing area in order to compress the powder.

3. The apparatus according to claim 1, wherein the lateral surfaces are configured to roll in contact with one another in the pressing area.

4. The apparatus according to claim 1, wherein the two rotatable roller elements comprise a first roller element and a second roller element, the cam mechanism has a cam element that is off-center with respect to a first axis of rotation of

the first roller element and is arranged within the first roller element, the plurality of moulding elements of the first roller element are radially deflectable by the cam element.

5. The apparatus according to claim 4, wherein the cam element is rotationally symmetric with respect to a cam axis that is offset with respect to the first axis of rotation of the first roller element.

6. The apparatus according to claim 4, wherein the first roller element has guide channels that extend radially inward from a lateral surface of the first roller element such that the plurality of moulding elements of the first roller element are guided within the guide channels and the guide channels receive the powder upon reaching the pressing area.

7. The apparatus according to claim 6, wherein the guide channels are configured for granules to be formed therewithin.

8. The apparatus according to claim 6, wherein the cam mechanism is configured to deflect the plurality of molding elements of the first roller element radially outward after leaving the pressing area such that the granules are ejected from the guide channels.

9. The apparatus according to claim 1 further comprising a separating apparatus positioned beneath the two rotatable roller elements, wherein the separating apparatus is configured to collect and separate granules and the powder after leaving the pressing area.

10. The apparatus according to claim 9 further comprising a return device configured to return the powder separated from the granules by the separating

apparatus to a storage container of the feed apparatus.

11. An apparatus for treatment of a residual thermoplastic powder from an additive manufacturing process, the apparatus comprising:

- a feed apparatus for feeding a powder, wherein the powder includes the residual thermoplastic powder;
- a first roller element and a second roller element, wherein the first and second roller elements are drivable in opposite rotational directions, each of the first and second roller elements have a lateral surface adjacent to and in contact with one another in a pressing area, and the lateral surfaces of the first and second roller elements each having a plurality of moulding elements assigned to one another in pairs such that the powder fed into the pressing area by the feed apparatus is compressed into granules; and
- a cam mechanism configured to deflect the plurality of moulding elements of the first roller element radially as a function of an angle of rotation of the first roller element.

12. The apparatus according to claim 11, wherein the cam mechanism is configured to deflect the plurality of moulding elements of the first roller element radially outward in the pressing area such that the powder in the pressing area is compressed.

13. The apparatus according to claim 11, wherein the cam mechanism has a cam element arranged within the first roller element, the cam element is arranged off-

center with respect to a first axis of rotation of the first roller element, and the plurality of moulding elements of the first roller element are radially deflectable by the cam element.

14. The apparatus according to claim 13, wherein the cam element is rotationally symmetric with respect to a cam axis that is offset with respect to the first axis of rotation of the first roller element.

15. The apparatus according to claim 14, wherein the first roller element has guide channels that extend radially inward from the lateral surface of the first roller element such that the plurality of molding elements of the first roller element are guided within the guide channels and the guide channels receive the powder upon reaching the pressing area.

16. The apparatus according to claim 15, wherein the cam mechanism is configured to deflect the plurality of molding elements of the first roller elements radially outward after leaving the pressing area such that the granules are ejected from the guide channels.

17. An apparatus for treatment of a residual thermoplastic powder from an additive manufacturing process, the apparatus comprising:

- a feed apparatus for feeding a powder, wherein the powder includes the residual thermoplastic powder from the additive manufacturing process;
- a first roller element and a second roller element, wherein the first and second roller elements are drivable in opposite rotational directions, each of the first and second roller elements have a lateral

surface adjacent to and in contact with one another in a pressing area, and the lateral surfaces of the first and second roller elements each have a plurality of moulding elements assigned to one another in pairs; and

- a cam mechanism configured to deflect the plurality of moulding elements of the first roller element radially outward as a function of an angle of rotation of the first roller element.

18. The apparatus according to claim 17, wherein the cam mechanism has a cam element arranged within the first roller element, the cam element is rotationally symmetric with respect to a cam axis that is offset with respect to a first axis of rotation of the first roller element, and the plurality of moulding elements of the first roller element are radially deflectable by the cam element.

19. The apparatus according to claim 18, wherein the first roller element has guide channels that extend radially inward from the lateral surface of the first roller element such that the plurality of moulding elements of the first roller element are guided within the guide channels.

20. The apparatus according to claim 19, wherein the cam mechanism is configured to deflect the plurality of moulding elements of the first roller elements radially outward after leaving the pressing area such that the granules are ejected from the guide channels

9. Abstract:

[00133] An apparatus for the treatment of residual thermoplastic powder from an additive manufacturing process includes a feed apparatus for feeding powder, which includes the residual thermoplastic powder, to a pressing area, and two rotatable roller elements which are drivable in opposite directions. Lateral surfaces of the two rotatable roller elements are adjacent to one another in a pressing area and each laterally have a plurality of moulding elements that are assigned to one another in pairs in order to compress powder into granules in the pressing area. Also, a cam mechanism is included and configured to deflect the moulding elements of one of the two rotatable roller elements radially depending on the angle of rotation.

CONCLUSION

[00134] With this thesis is shown that additive manufacturing has several environmental issues, it´s often said that Additive Manufacturing is good for the environment as we only use the material that we need to print the parts, this is not completely true. As shown in this thesis some of the leftover powder will be disposed, and the costs are immense. Any powder that is stuck to the part is waste, the rest can be reused to a maximum 50/50 or 70/30 depending on the material specifications.

[00135] The research shown in this thesis have culminated to a Nobel process of recycling the waste powder, using an apparatus developed specially for the process, reducing processing cost, and optimizing material properties.

[00136] In my opinion we need to be aware and educate the engineering community as soon as possible that there is too much waste in additive manufacturing process, especially when is used filled material like glass fiber, carbon fiber or aluminum. We should avoid such materials, only used in special application under control.

[00137] With these two patents we can solve part of the issue, reusing the material in high injection process, but this is only a solution for the waste, not a solution to avoid the waste creation. We should develop new additive manufacturing processes that don´t create waste at this pace, or improving the current state of the art. For example, the HP released the multi Jet Fusion, that was really a great development reducing the amount of virgin powder required to 25%. Nevertheless, that still means we create 10% waste.

[00138] These two patents disclosures were record under Ford Motor Company, that support all my work and research.

[00139] I would like to acknowledge Ford Motor company, especially rapid Technology Center for supporting further research in sustainable technologies, and to give all engineers tools to do science.

Appendices

Appendix A: Patent Application registration in Germany: Verfahren zur Aufbereitung von thermoplastischen Restpulvern

Deutsches
Patent- und Markenamt

Deutsches Patent- und Markenamt
elektronische Dokumentenannahme

Benachrichtigung über den Eingang einer Patentanmeldung mit der epoline®-Software für die Online-Einreichung

epoline Einreichungsnummer:	800699469	
Anmeldung eingegangen am:	11 März 2019	
Anmeldung erhalten von:	epoline®-Software für die Online-Einreichung	
Ihr Zeichen:	218-0261DE	
Digitale Signatur:	0A:93:A3:C3:91:4F:42:EC:CA:E6:C0:CE:FD:21:E5:94:6C:52:1A:D3	
Eigentümer:	CN=Thomas Dörfler 2831	
Seriennummer:	141215031402924683208077914806424226283	
Herausgeber:	CN=European Patent Office CA G2,O=European Patent Office	
Daten zum vorliegenden Vorgang:		
Amtliches Aktenzeichen:	102019203285.0	
Vorgangstyp:	Patentanmeldung	
Anmeldeamt:	Deutsches Patent- und Markenamt	
Titel der Patentanmeldung:	Verfahren zur Aufbereitung von thermoplastischen Restpulvern	
Anmelder:	Ford Global Technologies, LLC	
Folgende Dateien sind beim Deutschen Patent- und Markenamt eingegangen und wurden auf korrekte Syntax, Vollständigkeit der Anmeldedaten und zulässige Graphikformate erfolgreich validiert:	package-data.xml	de-request.xml
	de-request.pdf	directdebit.pdf
	directdebit.xml	inventor.pdf
	SPECIFICATION.pdf	drawing-1.pdf

Appendix B: Patent disclosure registration in Germany: Vorrichtung zur Aufbereitung von thermoplastischen Restpulvern

Deutsches
Patent- und Markenamt

Deutsches Patent- und Markenamt
elektronische Dokumentenannahme

Benachrichtigung über den Eingang einer Patentanmeldung mit der epoline®-Software für die Online-Einreichung

epoline Einreichungsnummer:	800699468	
Anmeldung eingegangen am:	11 März 2019	
Anmeldung erhalten von:	epoline®-Software für die Online-Einreichung	
Ihr Zeichen:	218-0263DE	
Digitale Signatur:	B8:FC:1D:41:8B:D8:0E:E8:29:41:E4:EB:66:C8:E0:32:18:EF:3D:28	
Eigentümer:	CN=Thomas Dörfler 2831	
Seriennummer:	141215031402924683208077914806424226283	
Herausgeber:	CN=European Patent Office CA G2,O=European Patent Office	
Daten zum vorliegenden Vorgang:		
Amtliches Aktenzeichen:	102019203284.2	
Vorgangstyp:	Patentanmeldung	
Anmeldeamt:	Deutsches Patent- und Markenamt	
Titel der Patentanmeldung:	Vorrichtung zur Aufbereitung von thermoplastischem Restpulver	
Anmelder:	Ford Global Technologies, LLC	
Folgende Dateien sind beim Deutschen Patent- und Markenamt eingegangen und wurden auf korrekte Syntax, Vollständigkeit der Anmeldedaten und zulässige Graphikformate erfolgreich validiert:	package-data.xml	de-request.xml
	de-request.pdf	directdebit.pdf
	directdebit.xml	inventor.pdf
	SPECIFICATION.pdf	drawing-1.pdf