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# mes Training Curriculums

INDI4.0 Project Stuttgart | 06/2021 Workshop documents Intellectual Output “O1”

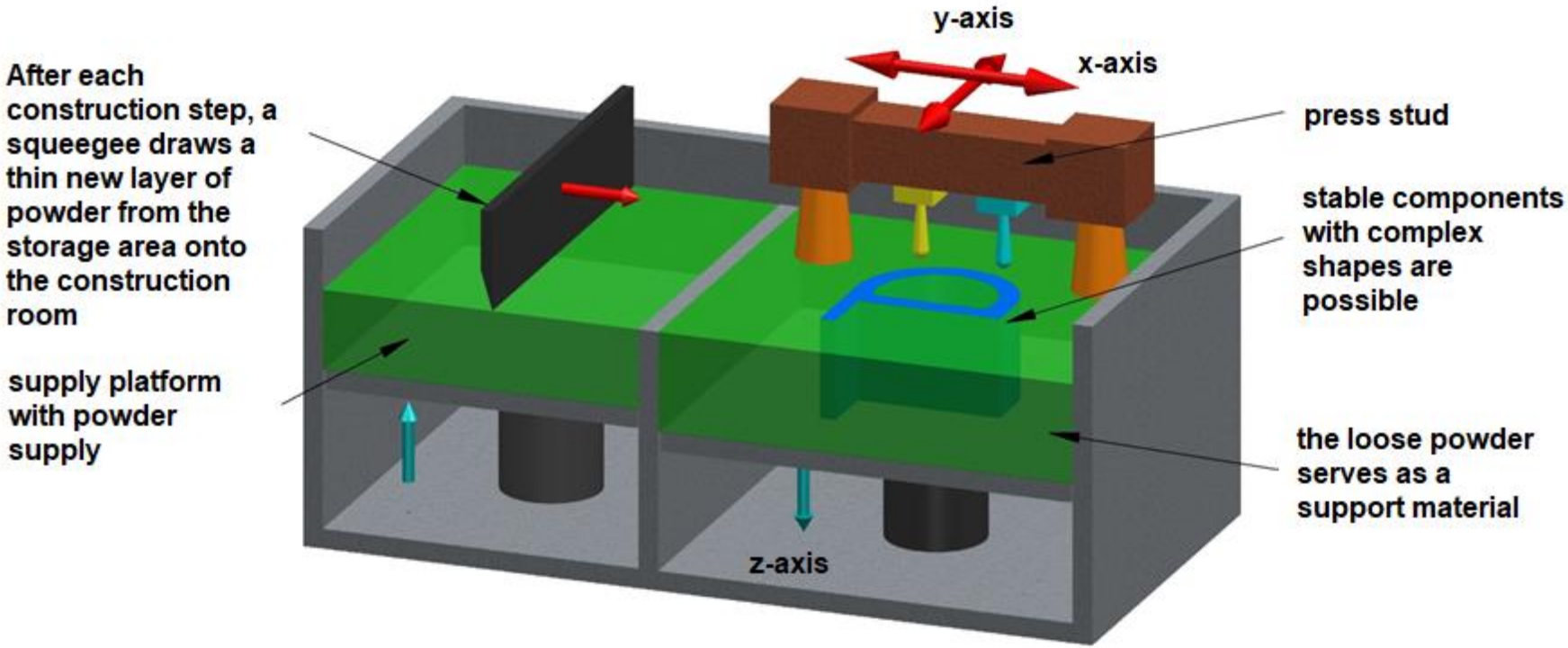
## Additive manufacturing

Existing additive manufacturing equipment

| | |
|---|---|
| Stratasys dimension sst 1200es | (FDM) |
| Stratasys objet350 connex3 | (Polyjet Tech.) |
| Trumpf TruPrint 1000 | |

## Worksheet 1:

**Process: Multi Jet Fusion (Multi Jet Fusion - MJF)**

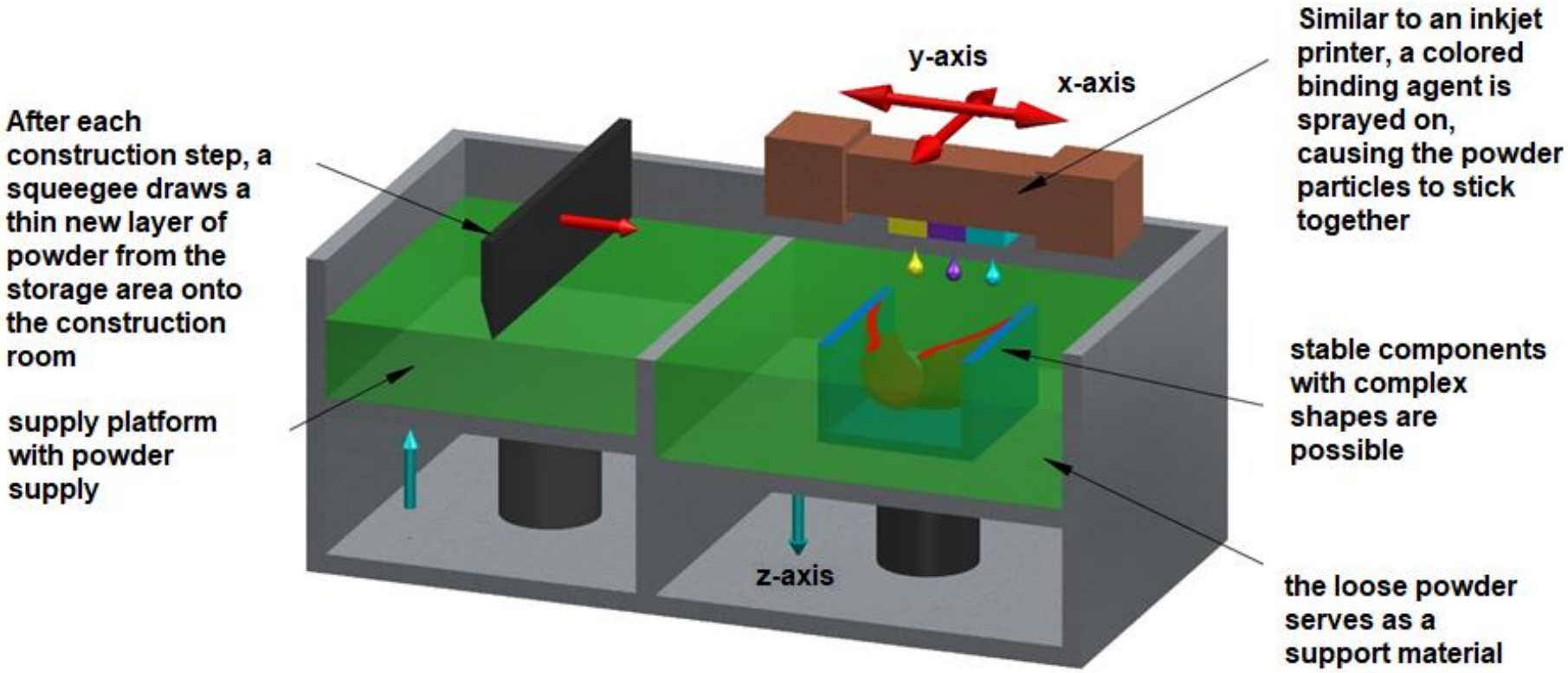


| | |
|---|---|
| Determine the following information with the help of an Internet search: | |
| How the procedure works: | |
| Materials: | • |
| Material properties: | • |
| Advantages: | • <br> • <br> • |
| Disadvantage: | • <br> • <br> • |
| Accuracy: | • |
| Areas of application: | • |

• Present your result with an explanation of how the procedure works.

## Worksheet 2:

**Process: Powder printing - (3D Printing - 3DP or Binder Jetting - BJ)**

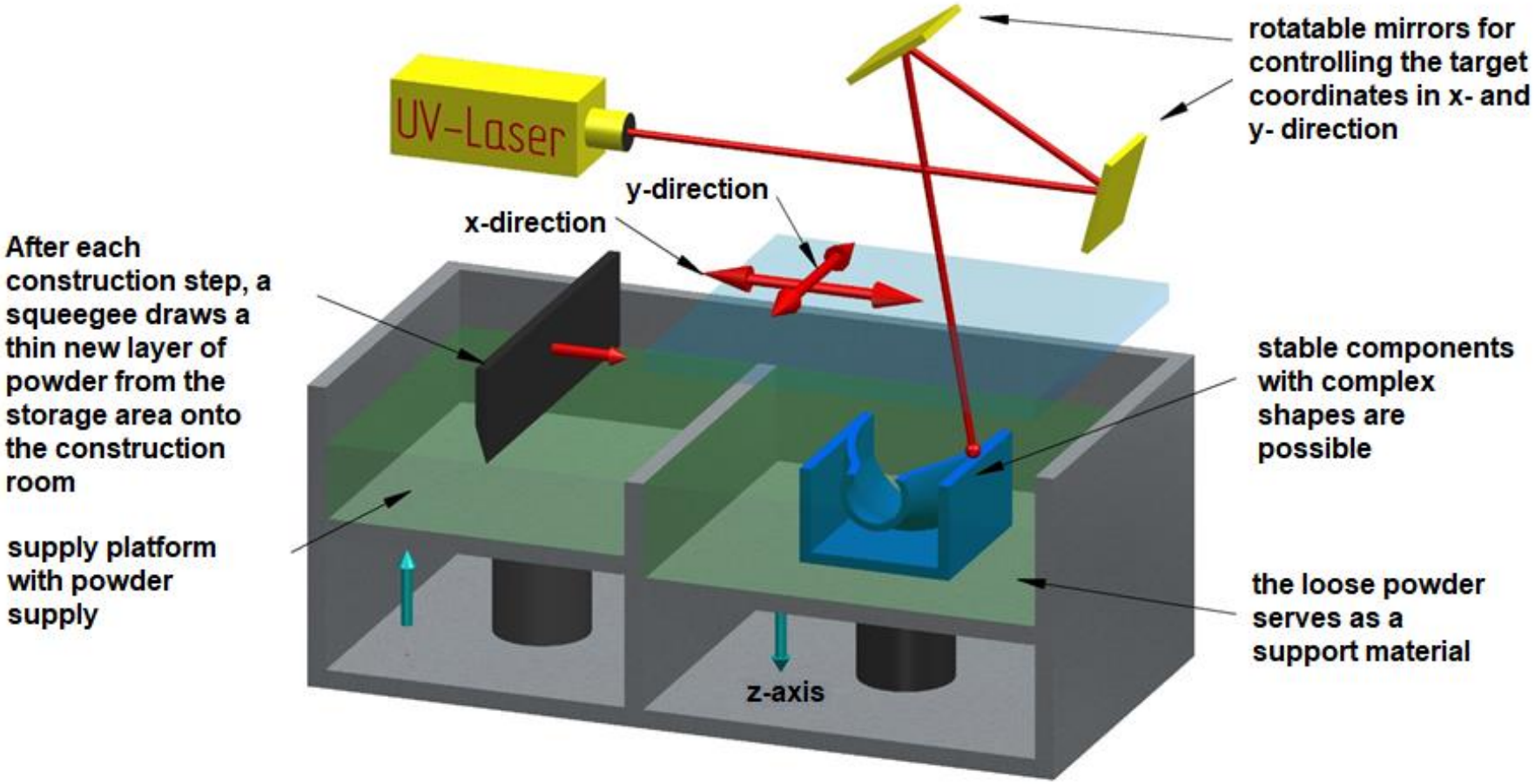


| Determine the following information with the help of an Internet search: | |
|---|---|
| <u>How the procedure works:</u> | |
| Materials: | • |
| Material properties: | • |
| Advantages: | • <br> • <br> • |
| Disadvantage: | • <br> • <br> • |
| Accuracy: | • |
| Areas of application: | • |

• Present your result with an explanation of how the procedure works.

## Worksheet 3:

**Process: Selective Laser Sintering (SLS)**

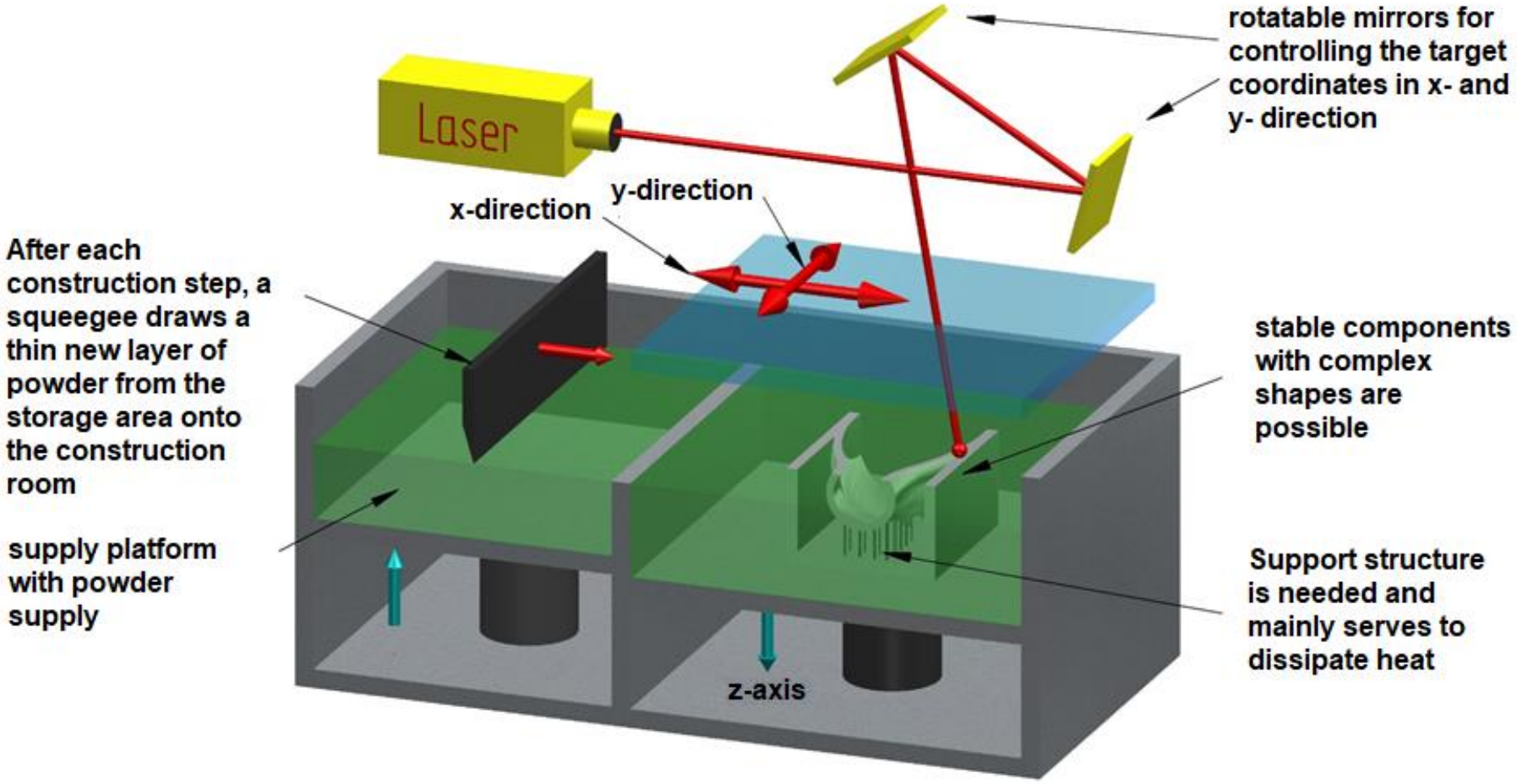


| Determine the following information with the help of an Internet search: | |
|---|---|
| <u>How the procedure works:</u> | |
| Materials: | • |
| Material properties: | • |
| Advantages: | • <br> • <br> • |
| Disadvantage: | • <br> • <br> • |
| Accuracy: | • |
| Areas of application: | • |

• Present your result with an explanation of how the procedure works.

## Worksheet 4:

**Process: Selective Laser Melting (SLM)**

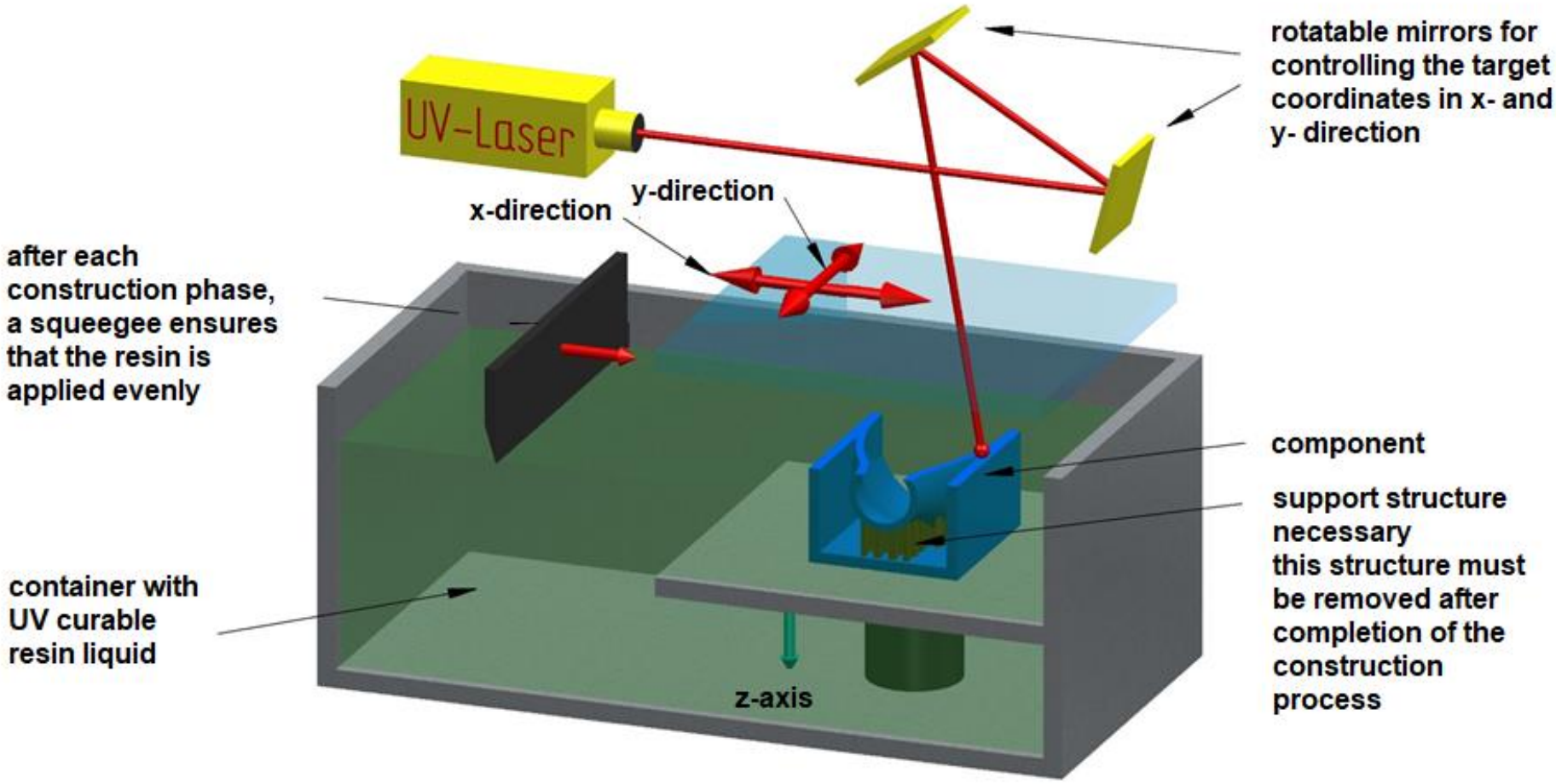


| Determine the following information with the help of an Internet search: | |
|---|---|
| <u>How the procedure works:</u> | |
| Materials: | • |
| Material properties: | • |
| Advantages: | • <br>• <br>• |
| Disadvantage: | • <br>• <br>• |
| Accuracy: | • |
| Areas of application: | • |

• Present your result with an explanation of how the procedure works.

## Worksheet 5:

**Process: Stereolithography (SLA)**

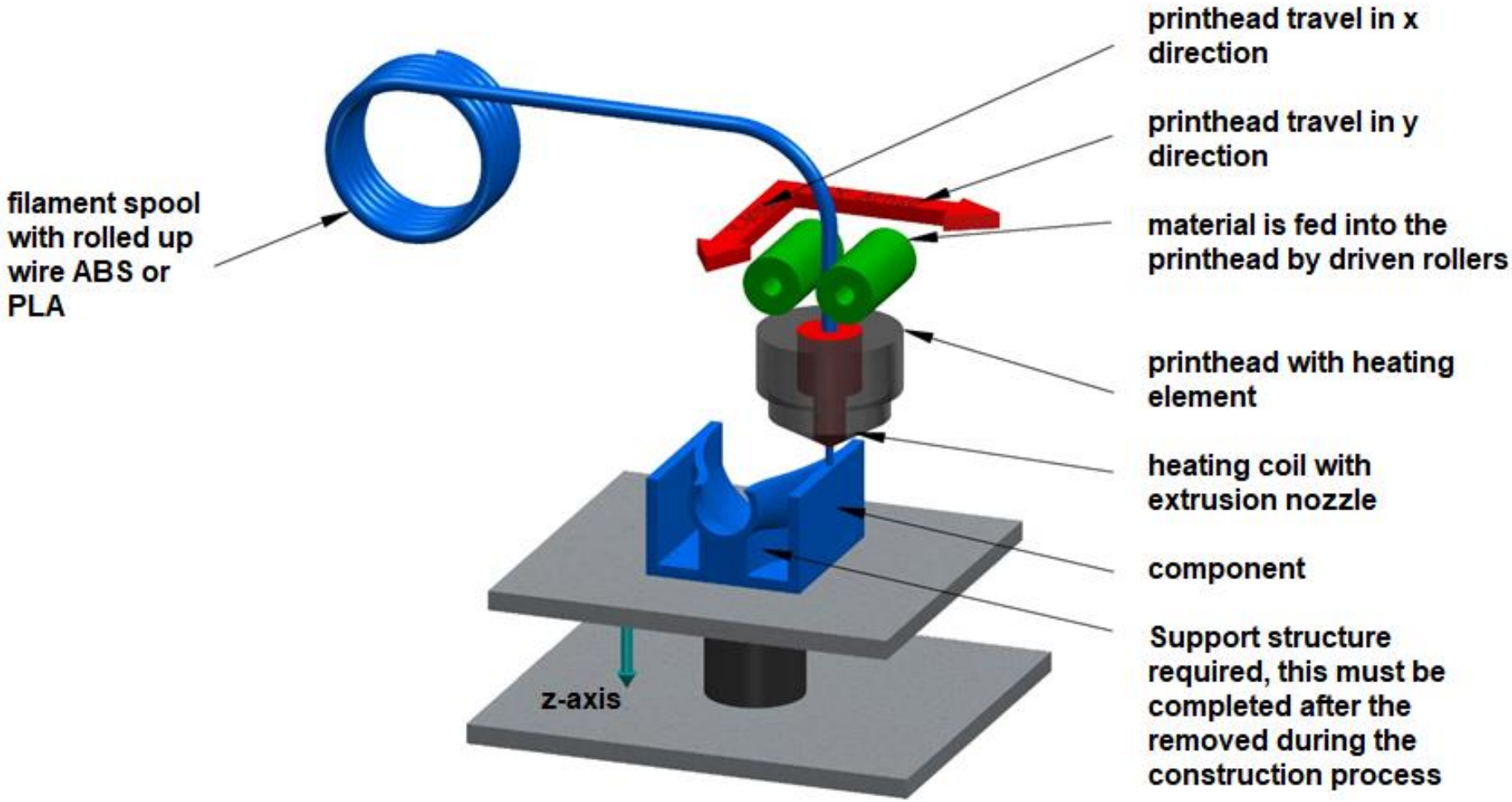


| Determine the following information with the help of an Internet search: | |
|---|---|
| <u>How the procedure works:</u> | |
| Materials: | • |
| Material properties: | • |
| Advantages: | • <br> • <br> • |
| Disadvantage: | • <br> • <br> • |
| Accuracy: | • |
| Areas of application: | • |

• Present your result with an explanation of how the procedure works.

## Worksheet 6:

**Process: Fused Deposition Modeling (FDM) Melt layering with a nozzle**

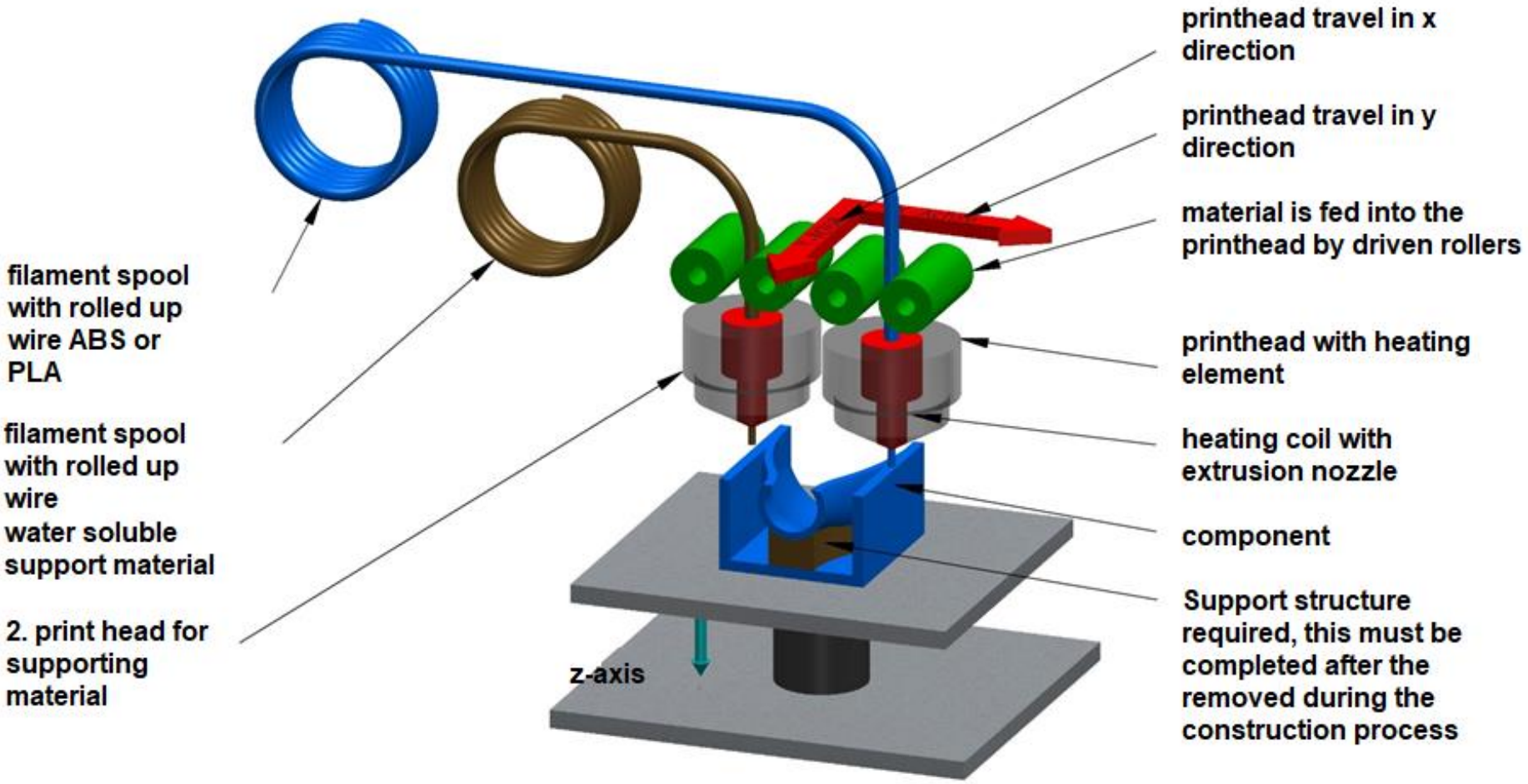


| Determine the following information with the help of an Internet search: | |
|---|---|
| <u>How the procedure works:</u> | |
| Materials: | • |
| Material properties: | • |
| Advantages: | • <br> • <br> • |
| Disadvantage: | • <br> • <br> • |
| Accuracy: | • |
| Areas of application: | • |

• Present your result with an explanation of how the procedure works.

## Worksheet 7:

**Process: Fused Deposition Modeling (FDM) Melt layering with two nozzles**

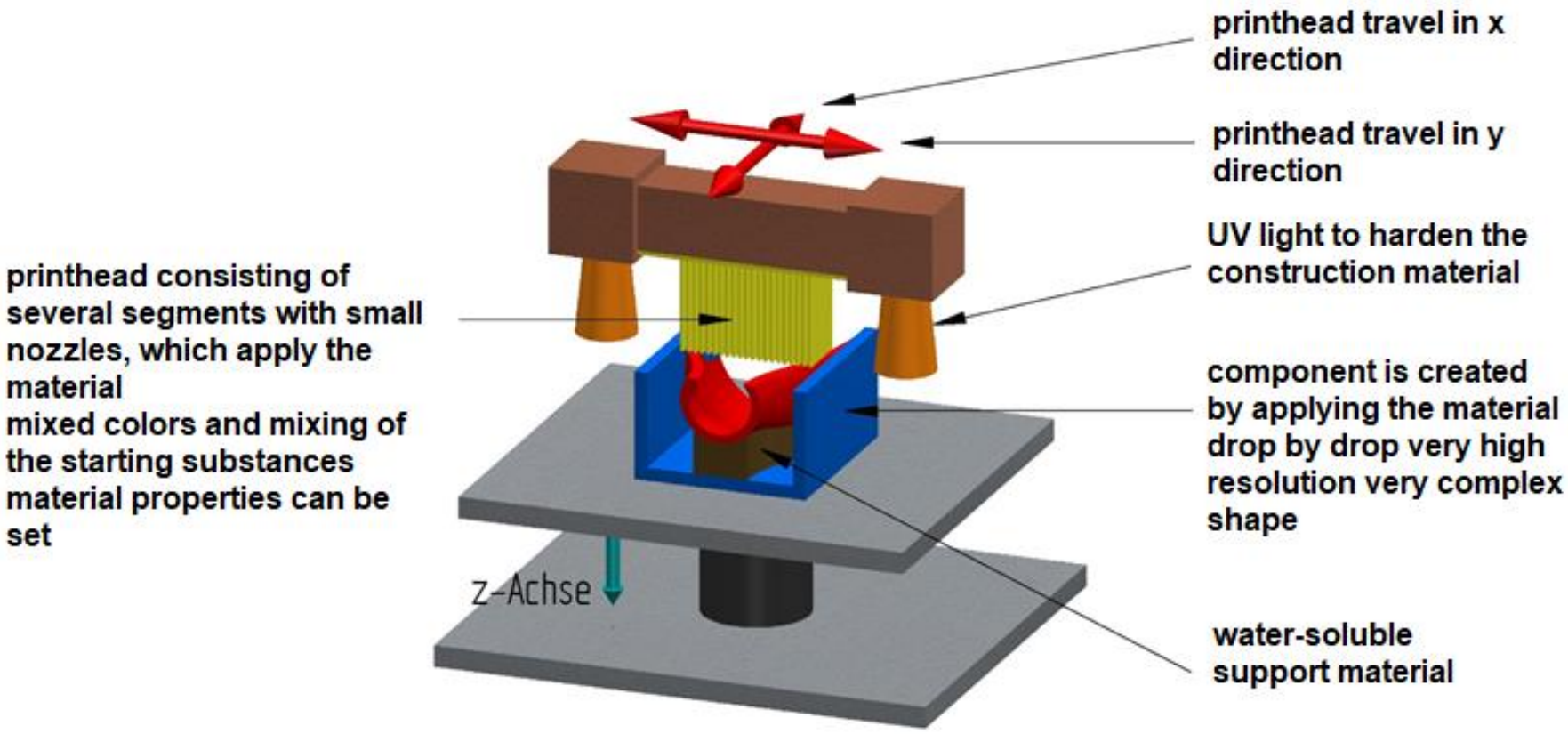


| Determine the following information with the help of an Internet search: | |
|---|---|
| <u>How the procedure works:</u> | |
| Materials: | • |
| Material properties: | • |
| Advantages: | • <br> • <br> • |
| Disadvantage: | • <br> • <br> • |
| Accuracy: | • |
| Areas of application: | • |

• Present your result with an explanation of how the procedure works.

## Worksheet 8:

**Process: Polyjet process; Multi-Jet Modeling (MJM)**

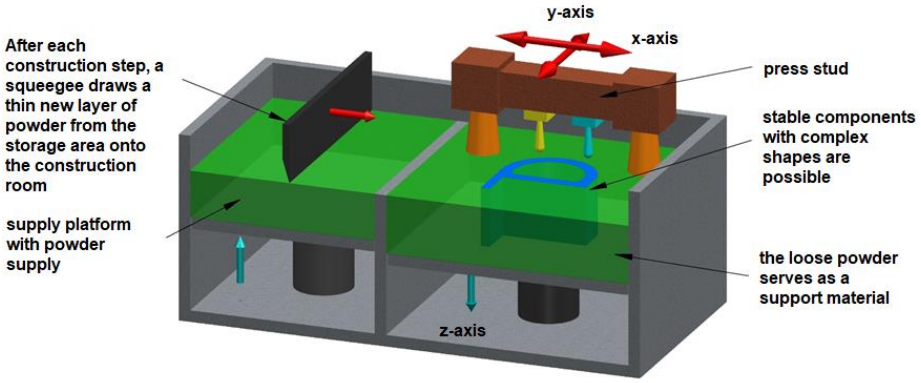


| Determine the following information with the help of an Internet search: | |
|---|---|
| <u>How the procedure works:</u> | |
| Materials: | • |
| Material properties: | • |
| Advantages: | • <br> • <br> • |
| Disadvantage: | • <br> • <br> • |
| Accuracy: | • |
| Areas of application: | • |

• Present your result with an explanation of how the procedure works.

## Solution to worksheet 1:

### Process: Multi Jet Fusion (Multi Jet Fusion - MJF)




Working method:

Polyamide powder is melted by a liquid and heat.

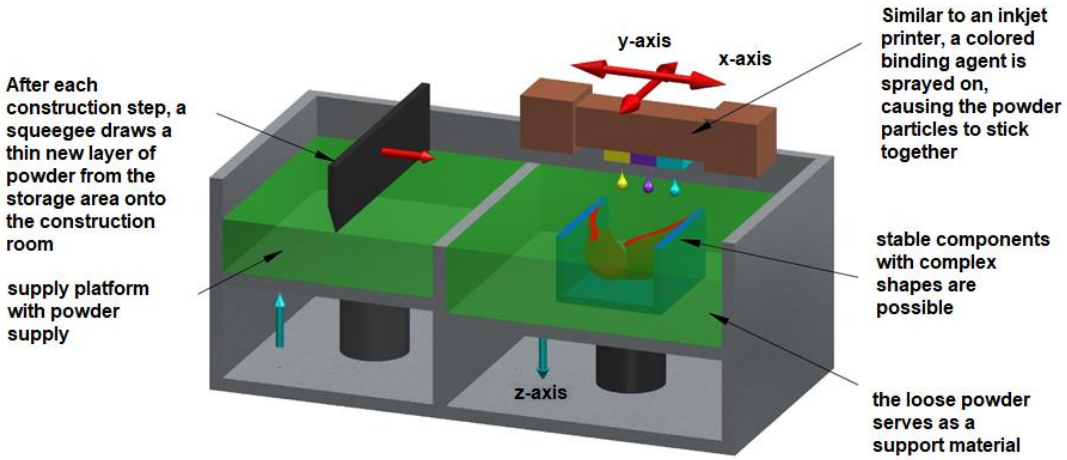
Similar to an inkjet printer, different liquids are applied, one liquid being thermally conductive and one being insulating. The thermally conductive liquid binds the powder with the help of the heat from UV lamps

| Determine the following information with the help of an Internet search: | |
|---|---|
| Materials: | • Polyamide - PA12 (nylon) |
| Material properties: | • Resistant to oil, grease, hydrocarbons, alkalis |
| Advantages: | • Mechanically and thermally resilient components with a high component density and complex shape<br>• No support structures are required<br>• very fast manufacturing process |
| Disadvantage: | • rough surfaces<br>• only single-color models are possible |
| Accuracy: | • Low level of detail, ± 0.3 mm |
| Areas of application: | • Production of functional parts |

• Present your result with an explanation of how the procedure works.

## Solution to worksheet 2:

### Process: Powder printing - (3D Printing - 3DP or Binder Jetting - BJ)




Working method:

Similar to an inkjet printer, a colored liquid is sprayed on as a binding agent.

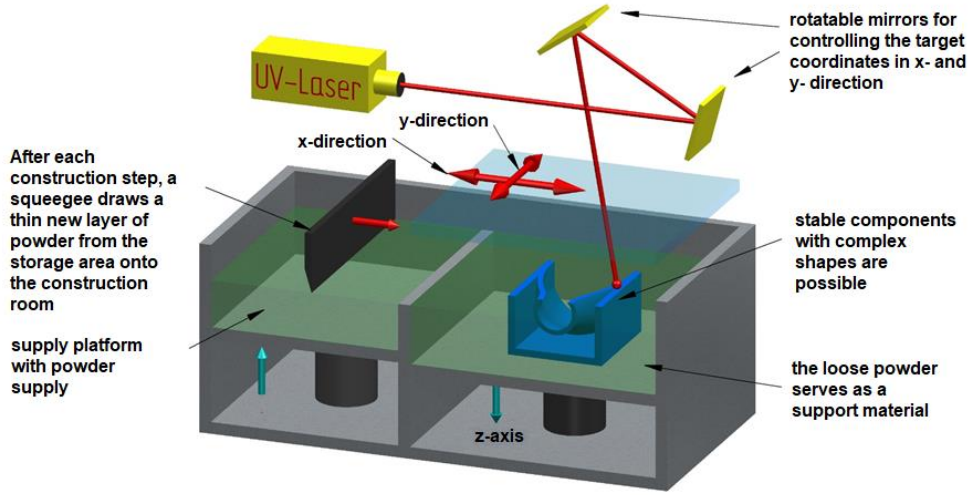
The powder is bound by glue, supporting structures are not required. The unbound powder serves as a support structure.

| Determine the following information with the help of an Internet search: | |
|---|---|
| Materials: | • almost any material that is in powder form and can be solidified with a suitable adhesive as a binding agent |
| Material properties: | • Average resistance of the components |
| Advantages: | • fast production<br>• Complex shapes possible, no support structures necessary<br>• full-color models can be displayed |
| Disadvantage: | • Mechanically only moderately resilient components<br>• slightly rough surface, like sandblasted<br>• Rework necessary (remove powder) |
| Accuracy: | • Average level of detail, ± 0.13 mm, smallest slice thickness 0.09 mm |
| Areas of application: | • Illustrative models, prototypes |

• Present your result with an explanation of how the procedure works.

## Solution to worksheet 3:

### Process: Selective Laser Sintering (SLS)




Working method:

After applying a thin layer of powder, it is selectively melted by a laser.

The parts are built up layer by layer in the powder bed, with the non-melted powder serving as a support structure.

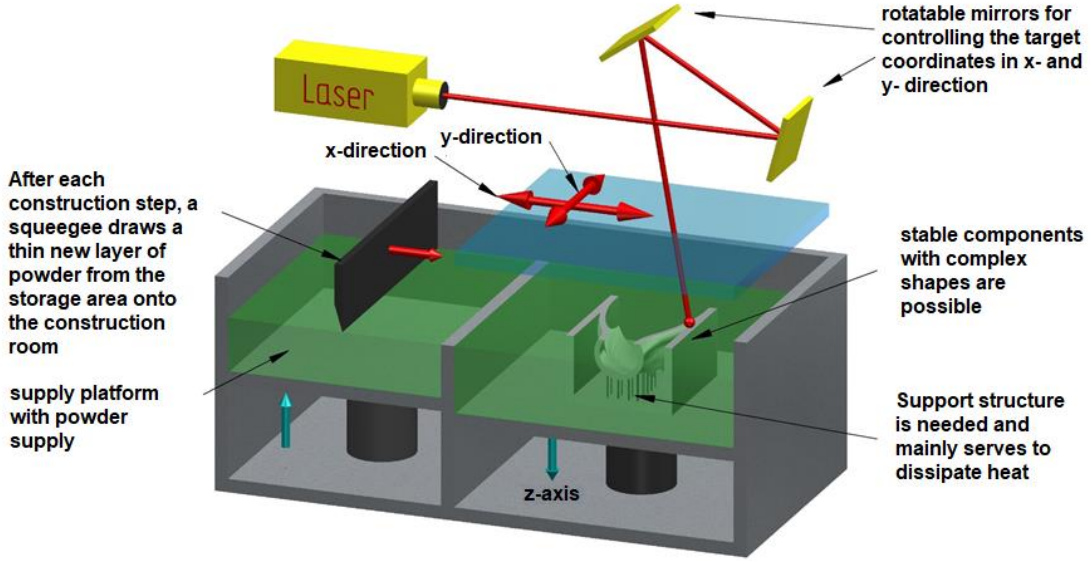
After each shift, the building platform is lowered by one layer.

| Determine the following information with the help of an Internet search: | |
|---|---|
| Materials: | • Different polyamide blends (PA2200, PA12MD etc.) |
| Material properties: | • good resistance |
| Advantages: | • Mechanically and thermally resilient components<br>• Complex shapes possible, no support structures required<br>• flexible components, variety of materials |
| Disadvantage: | • slightly rough surface<br>• Slow manufacturing process, reworking necessary<br>• only single-color models possible |
| Accuracy: | • ± 0.25 mm |
| Areas of application: | • Prototypes, parts for functional tests, small series |

• Present your result with an explanation of how the procedure works.

## Solution to worksheet 4:

### Process: Selective Laser Melting (SLM)




Working method:

After applying a thin layer of powder (metal), it is selectively melted by a laser (fiber laser). The components are built up layer by layer in the powder bed. After each shift, the building platform is lowered by one layer.

A support structure towards the construction platform is required, which is mainly used to dissipate heat, since the process introduces a great deal of heat into the component, which usually causes it to warp.

The support structure must be separated after completion of the construction process. SLM components are usually reworked subtractively.

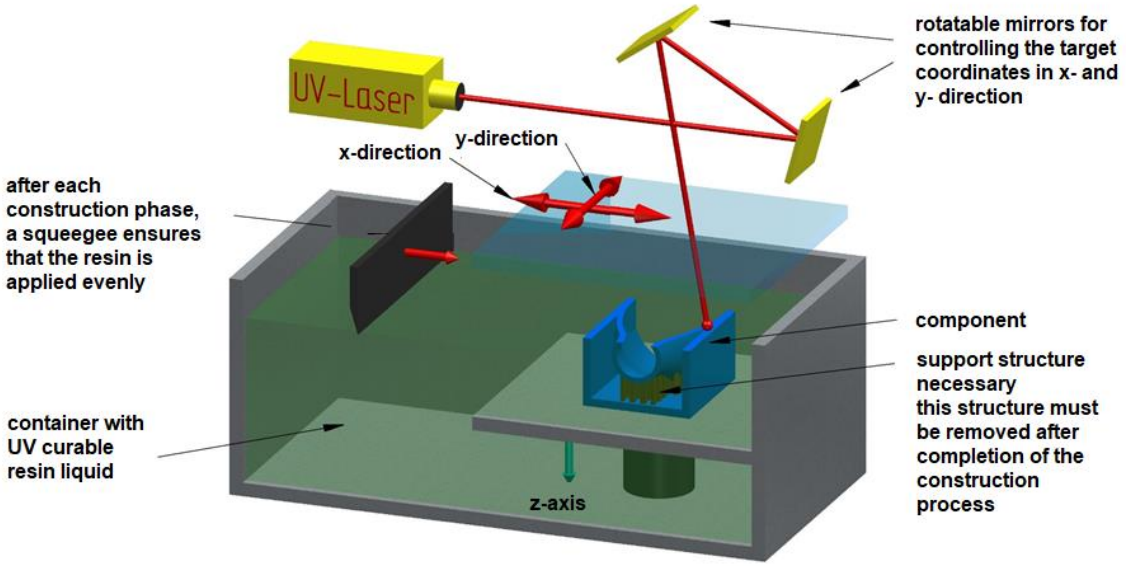
The powder must be handled very carefully, protective equipment is required, as the powders are hazardous to health due to their very small particle size.

| Determine the following information with the help of an Internet search: | |
|---|---|
| Materials: | • Powder from stainless steel, tool steel, cobalt-chromium, aluminum, nickel-based alloy, bronze, titanium, silver, gold |
| Material properties: | • Material properties similar to the compact material from which the powder was made |
| Advantages: | • Mechanically and thermally highly resilient components<br>• complex shapes possible<br>• high density (up to 99%) |
| Disadvantage: | • slightly rough surface<br>• In comparison to the additive manufacturing process, slower manufacturing process, reworking necessary<br>• Problematic handling of fine powder |
| Accuracy: | • ± 0.25 mm |
| Areas of application: | • Functional parts, small series, medical implant products |

• Present your result with an explanation of how the procedure works.

## Solution to worksheet 5:

### Process: Stereolithography (SLA)




Working method:

A liquid polymer is cured by a UV laser on the surface of a bath.

Then the build platform is lowered by one layer and the next layer can be cured.

Support structures must be built from the same material and mechanically removed after the building process.

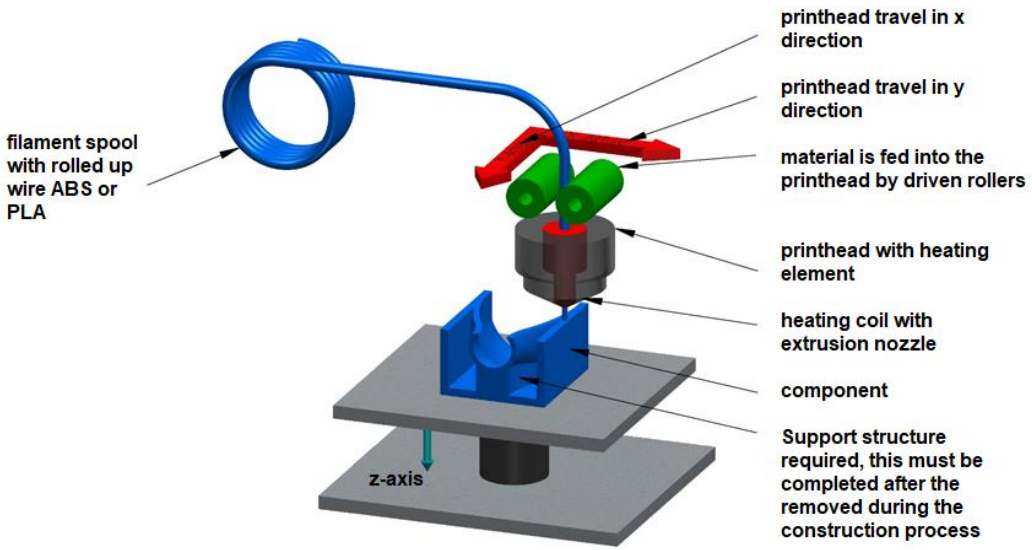
Post-curing in a UV oven is recommended in order to achieve complete polymerization.

| Determine the following information with the help of an Internet search: | |
|---|---|
| Materials: | • Only photopolymers that cure under UV light / heat can be processed |
| Material properties: | • only limited resistance, material ages over time and loses mechanical and geometric properties |
| Advantages: | • very detailed and fine surfaces, complex shapes<br>• partially mechanically resilient when the component is completely hardened<br>• transparent components are possible |
| Disadvantage: | • only UV-curable plastics / resins can be used, high manufacturing costs, slow process<br>• In comparison to the additive manufacturing process, limited mechanical and thermal load capacity<br>• only single-colored models with support structures, which have to be removed afterwards |
| Accuracy: | • high accuracy, ± 0.15 mm, smallest layer thickness 0.016 mm |
| Areas of application: | • Prototypes with a good surface and fine details for visual tests, master models for traditional processes |

• Present your result with an explanation of how the procedure works.

## Solution to worksheet 6:

### Process: Fused Deposition Modeling (FDM) Melt layering with a nozzle




Working method:

A plastic wire is inserted into a heated nozzle, melted and extruded through the nozzle.

The components are built up by laying the melted plastic in layers.

Support structures are necessary and are made of the same material and must be removed mechanically after completion of the construction process.

Due to the layered structure, the accuracy in the Z-direction is lower and a step-like structure can arise.

The material properties in the Z direction are also worse than in the X and Y directions.

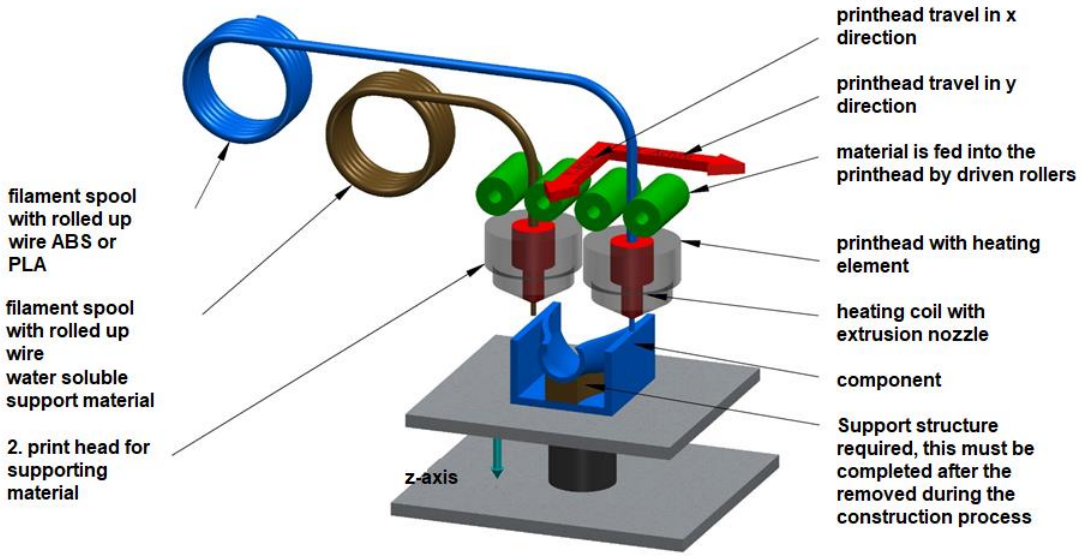
The component must be aligned in the installation space in such a way that the material properties and accuracy of the process are optimally used.

| Determine the following information with the help of an Internet search: | |
|---|---|
| Materials: | • Thermoplastics such as PC and ABS |
| Material properties: | • In comparison to the additive manufacturing process, good resistance, good mechanical properties |
| Advantages: | • In comparison to the additive manufacturing process, inexpensive components<br>• In comparison to the additive manufacturing process, resistant components |
| Disadvantage: | • Only surfaces with grooves are possible, medium manufacturing accuracy<br>• only monochrome models, support structures are necessary and require rework<br>• Compared to additive manufacturing processes, the manufacturing process is very slow |
| Accuracy: | • depending on the wire thickness, ± 0.2 mm to ± 0.5 mm |
| Areas of application: | • Functional parts and prototypes, small series |

• Present your result with an explanation of how the procedure works.

## Solution to worksheet 7:

### Process: Fused Deposition Modeling (FDM) Melt layering with two nozzles




Working method:

A plastic wire is inserted into a heated nozzle, melted and extruded through the nozzle.

The components are built up by laying the melted plastic in layers.

Support structures are created in a second nozzle in the same way, but from a soluble material that can be removed in an ultrasonic lye bath in a reworking process.

Due to the layered structure, the accuracy in the Z-direction is lower and a step-like structure can arise.

The material properties in the Z direction are also worse than in the X and Y directions.

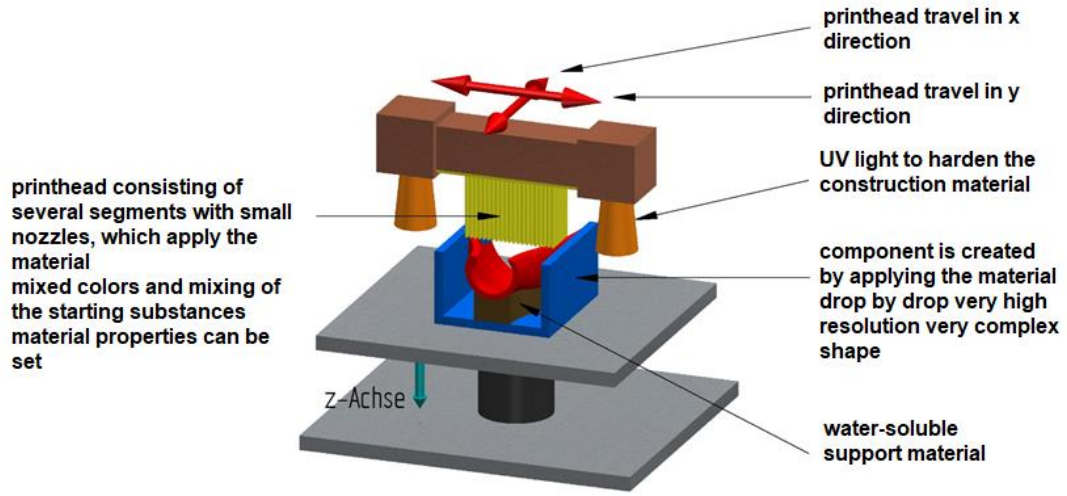
The component must be aligned in the installation space in such a way that the material properties and accuracy of the process are optimally used.

| Determine the following information with the help of an Internet search: | |
|---|---|
| Materials: | • Thermoplastics such as PC and ABS |
| Material properties: | • good resistance, good mechanical properties |
| Advantages: | • In comparison to the additive manufacturing process, inexpensive components<br>• In comparison to the additive manufacturing process, resistant components |
| Disadvantage: | • Only surfaces with grooves are possible, medium manufacturing accuracy<br>• only monochrome models, support structures are necessary and require rework<br>• Compared to additive manufacturing processes, the manufacturing process is very slow |
| Accuracy: | • depending on the wire thickness, ± 0.2 mm to ± 0.5 mm |
| Areas of application: | • Functional parts and prototypes, small series |

• Present your result with an explanation of how the procedure works.

## Solution to worksheet 8:

### Process: Polyjet process; Multi-Jet Modeling (MJM)




Working method:

Liquid photopolymers are applied in layers to a building platform using many print heads.

The photopolymers are cured by UV lamps after each layer applied.

By using many print heads, colors and material properties can be mixed when applying layers.

Support structures are necessary and are made of a separate material, which can be removed in a rework with a high pressure water jet in a blasting cabin.

| Determine the following information with the help of an Internet search: | |
|---|---|
| Materials: | • only photopolymers can be used |
| Material properties: | • Photopolymers with various colors and mechanical properties (Shore hardness) can be used and mixed |
| Advantages: | • High accuracy and smooth surfaces as well as transparent components are possible<br>• Different material properties can be combined on one component, flexible and rubber-like components are possible<br>• Fast manufacturing process compared to additive manufacturing processes |
| Disadvantage: | • Limited heat resistance of the components, components age and deteriorate in their properties<br>• High manufacturing costs compared to additive manufacturing processes<br>• Rework required to remove the support structures |
| Accuracy: | • very good, ± 0.025 mm, smallest layer thickness 0.016 mm |
| Areas of application: | • Prototypes in different colors, with good surfaces and partly rubber-like properties |

• Present your result with an explanation of how the procedure works.

Approximate values for the 3D printing accuracy solution

## General tolerances for length dimensions according to DIN ISO 2768-1

### 1. Category m (medium)

- Stereolithography (SLA)
- Polygraphy / photolithography
- Vacuum casting / injection molding
- CNC milling / laser cutting

### 2. Category c (coarse)

- Selective laser sintering (SLS)
- Selective laser melting (SLM)

### 3. Category v (very coarse)

- Fused Deposition Modeling (FDM)
- 2D printing with polymer plaster (3DP)

The following tolerance table shows an overview of the ISO 2768 standard, which is available as a DIN standard:

| | *Limiting dimension in mm for nominal dimension range in mm* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Tolerance class* | *up to 0.5* | *over 0.5 up to 3.0* | *over 3.0 to 6.0* | *over 6.0 to 30.0* | *over 30.0 to 120.0* | *over 120.0 up to 400.0* | *over 400.0 up to 1000.0* | *over 1000.0 up to 2000.0* | *over 2000.0 up to 4000.0* | *over 4000.0 to 8000.0* |
| m (medium) | n / a | ± 0.10 | ± 0.10 | ± 0.20 | ± 0.30 | ± 0.50 | ± 0.80 | ± 1.20 | ± 2.0 | ± 3.0 |
| c (coarse) | n / a | ± 0.15 | ± 0.20 | ± 0.50 | ± 0.80 | ± 1.20 | ± 2.0 | ± 3.0 | ± 4.0 | ± 5.0 |
| v (very coarse) | n / a | n / a | ± 0.50 | ± 1.00 | ± 1.50 | ± 2.5 | ± 4.0 | ± 6.0 | ± 8.0 | ± 8.0 |

## Manufacturing tolerances, orientation values for additive manufacturing

Source: https://www.rapidobject.com/de/Wissenswertes/3D-Druckverfahren_1173.html

| **Manufacturing technology / 3D printing process** | **Limiting dimensions in mm for nominal dimensions in mm** | |
|---|---|---|
| **Size range** | **up to 100 mm** | **from 100 mm** |
| Stereolithography SLA | ± 0.2 mm | ± 0.2% |
| Polygraphy / Polyjet | ± 0.1 mm | ± 0.2% |
| SLS / selective laser sintering | ± 0.3 mm | ± 0.3% |
| SLM / selective laser melting | ± 0.3 mm | ± 0.3% |
| SLM fine / selective laser melting | ± 0.1 mm | - |
| FDM / Fused Deposition Modeling | ± 0.2 mm | ± 0.15% |
| FDM large / Fused Deposition Modeling | ± 0.5 mm | ± 0.5% |

## Leading example bit box: selection of manufacturing processes

From the available additive manufacturing processes, the FDM process appears in principle suitable for manufacturing the components for the bit box.

However, it must be checked whether the relatively low manufacturing accuracy for clipping the components together can provide functional components. This must be checked by means of pressure tests.


Image: Example of a bit box (Image source Dr. Weltz, mes)

## Further information:

## Checklist for components for production on dimension sst 1200es:

| C: \ PC4_LW-C \ _mes_Wz_2019 \ LAK_Essl_2019-01-27 \ Documents_Wz \ [measurement_2017_11_08 (Wz V19a) .xlsx] conversion | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| No. | entry | worth | An H. | | worth | An H. | source | check |
| [-] | [-] | [-] | [-] | [-] | [-] | [-] | [-] | |
| 1 | Machine type | dimension sst 1200es | | | | | | |
| 2 | Minimum wall thicknessÄrke | 0.06 | inch | ≡ | 1.524 | mm | WORCESTER POLYTECHNIC INSTITUTE<br>100 Institute Road; Worcester, MA | |
| 3 | Installation spaceöße in X | 10 | inch | ≡ | 254 | mm | WORCESTER POLYTECHNIC INSTITUTE<br>100 Institute Road; Worcester, MA | |
| 4th | Installation spaceöße in Y | 10 | inch | ≡ | 254 | mm | WORCESTER POLYTECHNIC INSTITUTE<br>100 Institute Road; Worcester, MA | |
| 5 | Installation spaceöße in Z | 12th | inch | ≡ | 304.8 | mm | WORCESTER POLYTECHNIC INSTITUTE<br>100 Institute Road; Worcester, MA | |
| 6th | usable installation spaceöße in X | 9.9375 | inch | ≡ | 252.4125 | mm | WORCESTER POLYTECHNIC INSTITUTE<br>100 Institute Road; Worcester, MA | |
| 7th | usable installation spaceöße in Y | 9.9375 | inch | ≡ | 252.4125 | mm | WORCESTER POLYTECHNIC INSTITUTE<br>100 Institute Road; Worcester, MA | |
| 8th | usable installation spaceöße in Z | 11.5 | inch | ≡ | 292.1 | mm | WORCESTER POLYTECHNIC INSTITUTE<br>100 Institute Road; Worcester, MA | |
| 9 | Layer thickness | 0.01 | inch | ≡ | 0.254 | mm | WORCESTER POLYTECHNIC INSTITUTE<br>100 Institute Road; Worcester, MA | |
| 10 | accuracy | ± 0.006 | inch | ≡ | ± 0.1524 | mm | WORCESTER POLYTECHNIC INSTITUTE<br>100 Institute Road; Worcester, MA | |

| No. | entry | worth | An H. | | worth | An H. | source | check |
|---|---|---|---|---|---|---|---|---|
| [-] | [-] | [-] | [-] | [-] | [-] | [-] | [-] | |
| 11 | Accuracy (empirical value) deviations at größer components up to: | ± 0.012 | inch | ≡ | ± 0.3048 | mm | Dr. Weltz (mes) [Add. Man. Lab] | |
| 12th | Minimum distance between different components (assembly - pressure) | 0.01 | inch | ≡ | 0.254 | mm | WORCESTER POLYTECHNIC INSTITUTE 100 Institute Road; Worcester, MA | |
| 13th | Density setting - sparse (low density) | no influence on surfaceÄche | | | | | WORCESTER POLYTECHNIC INSTITUTE 100 Institute Road; Worcester, MA | |
| 14th | Density setting - sparse (high density) | no influence on surfaceÄche | | | | | WORCESTER POLYTECHNIC INSTITUTE 100 Institute Road; Worcester, MA | |
| 15th | Density adjustment solid | no influence on surfaceÄche | | | | | WORCESTER POLYTECHNIC INSTITUTE 100 Institute Road; Worcester, MA | |
| 16 | Density adjustment solid | only useful für very small parts | | | | | WORCESTER POLYTECHNIC INSTITUTE 100 Institute Road; Worcester, MA | |
| 17th | Definition of very small parts (2 dimensions smaller than) | 0.5 | inch | ≡ | 12.7 | mm | WORCESTER POLYTECHNIC INSTITUTE 100 Institute Road; Worcester, MA | |
| 18th | Direction of load bad (based on construction platform) | Z direction | | | | | WORCESTER POLYTECHNIC INSTITUTE 100 Institute Road; Worcester, MA | |
| 19th | Direction of load better (based on construction platform) | X and Y directions | | | | | WORCESTER POLYTECHNIC INSTITUTE 100 Institute Road; Worcester, MA | |

| No. | entry | worth | An H. | | worth | An H. | source | check |
|---|---|---|---|---|---|---|---|---|
| [-] | [-] | [-] | [-] | [-] | [-] | [-] | [-] | |
| 20th | General information:<br>On printed components:<br>Drilling, turning etc. | not recommendable | | | | | WORCESTER POLYTECHNIC INSTITUTE<br>100 Institute Road; Worcester, MA | |
| 21 | General information:<br>Printing waves, pens, etc. | not recommendable | | | | | WORCESTER POLYTECHNIC INSTITUTE<br>100 Institute Road; Worcester, MA | |