Chapter 3. Extrusion based additive processes

October 14, 2024

Fused Deposition Modelling (FDM)

3.1.1 Fused Deposition Modelling

Basic principle

- *A 3d part is built out of a molten amorphous thermoplastic wire extruded from a heated nozzle.*
- *The original and most suited material is ABS (**A**crylonitrile **B**utadiene **S**tyrene).*
- *The part is built lines by lines and layer by layer. The principle of consolidation is liquid phase bonding.*
- *The details of the part geometry are transferred into the process through the management of the nozzles (displacement and feed rates).*

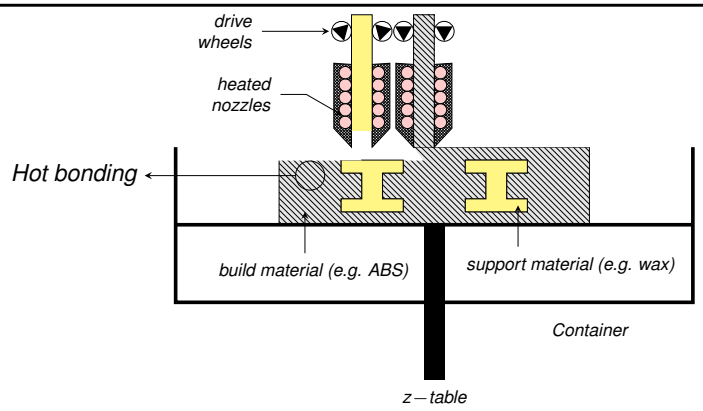
Acronym and remarks

- *This process is usually called FDM.*
- *FDM stations are generally equiped with two nozzles. The first one delivers the construction material (e.g. ABS) and the other a support material (typically wax).*

[1] Since they are less prone to shrinkage during re-solification, amorphous thermoplstics are better adapted to extrusion

3.1.2 Fused Deposition Modelling

Diagram



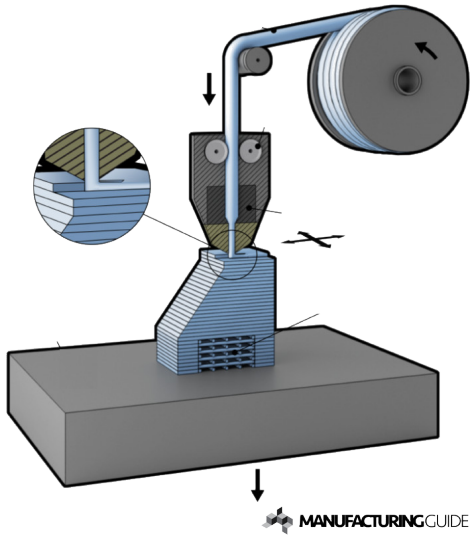
Remarks

- *The nozzles translate along both the x and y directions*

(see Append. 1)

3.1.3 Fused Deposition Modelling

Equipment

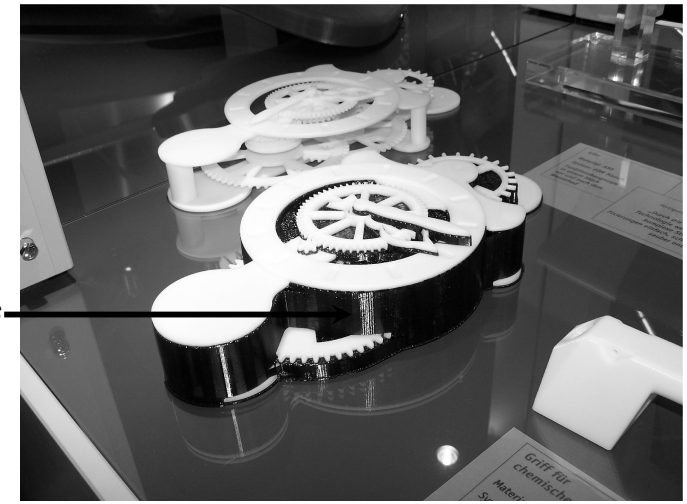


source: Stratasys™

3.1.4 Fused Deposition Modelling

Examples of parts

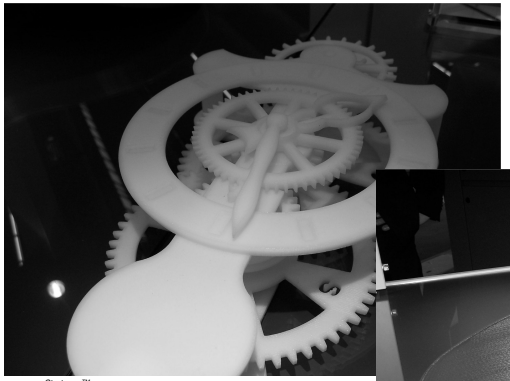
supports



source: Stratasys™

3.1.5 Fused Deposition Modelling

Examples of parts



source: Stratasys™

source: Stratasys™

3.1.6 Fused Deposition Modelling, technical data

Mechanical properties of part (order of magnitude)

Material	*E, GPa*	R_m, *MPa*	ε_{rup}, %
ABS plus P430	*2.3*	*37*	*3*
ULTEM 9085	*2.2*	*72*	*6*

Equipment (type, dimensions)

Build volume, mm^3		
from $250 \times 250 \times 300$	*to*	$915 \times 610 \times 915$

Performances

x-y resol., μm	***layer thickness***, μm	***build speed***, mm^3/s	***layering time***, *s*
130	*130-300*	*MCR* < 5	0[1]

[1] The fab. time only depends on the part volume: fab. time $= \frac{\text{volume}}{\text{MCR}}$

3.1.7 Fused Deposition Modelling

Companies

STRATASYS™, MAKERBOT™ , ULTIMAKER™, PRUSA™, REPRAP3D™, ...

Advantages

- *Simple, clean and safe operation, parts with gradient of properties possible.*
- *Patterns for the vacuum casting process, metallic or even ceramic parts possible.*
- *Fabrication of different type of custom items (shoes).*

Disadvantages

- *(Almost) exclusive use of ABS or PLA (now PET-G) due to their particular ability to make hot bonds on top of already existing cold parts (this property is mostly connected to a favourable combination of wettability and viscosity in liquid phase).*
- *Anisotropy of the part properties, less accurate then SLA or Polyjet.*
- *Relatively low manufacturing speed.*

(see Append. 2, 4)

"Ballistic Particle Manufacturing" (BPM)

3.2.1 Ballistic Particle Manufacturing

Basic principle

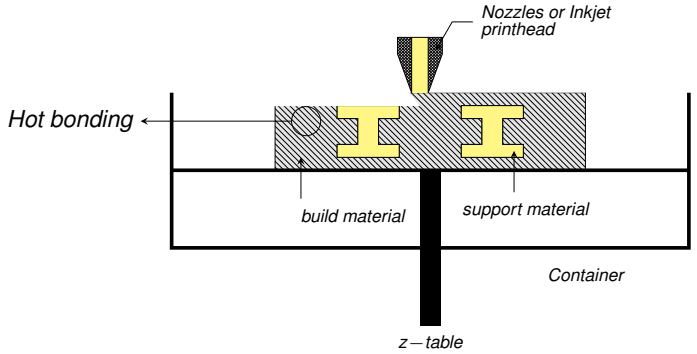
- *3D parts are manufactured out of droplets of molten wax delivered by an array of nozzles*
- *The part is built line by line and layer by layer. The principle of consolidation is liquid phase bonding*
- *The details of the part geometry are transferred into the process through the management of the nozzles (displacement and feed rates)*

Acronym and remarks

- *The acronym BPM is commonly used. It is also referred to as the MultiJet Manufacturing Process with acronym MJM.*
- *The nozzles deliver at least two different materials (construction/support). Support material has a lower melting point than the construction material.*
- *The material is not fused inside the nozzles. The molten wax is produced from the bulk in a separate containers and then injected to the nozzles. In particular, it means that the solid material to be extruded must not be delivered under the form of a filament like in FDM: abitrary and cheap pelets are enough. Moreover, since the nozzles do not need to be heated individually, it is possible to multiply them (print-head like).*

3.2.2 Ballistic Particle Manufacturing

Diagram



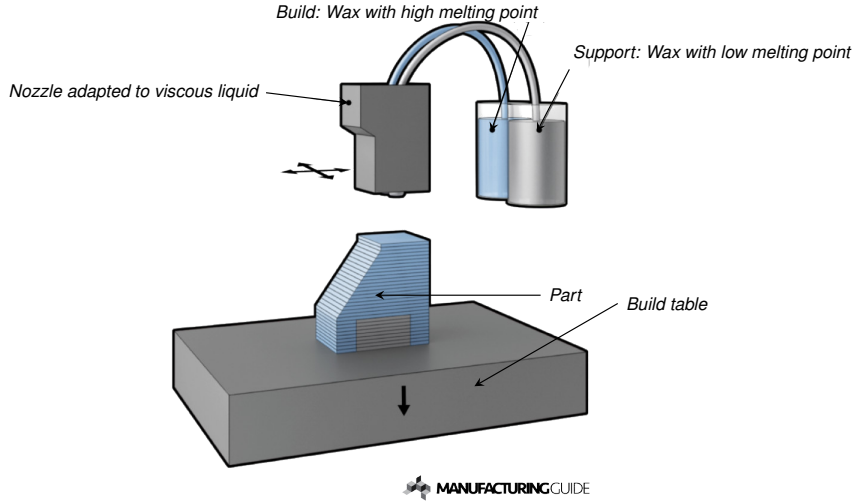
Remarks

- *Since they are not equipped with heating stages (unlike FDM) multiple nozzles side by side are possible (sort of inkjet printhead). The number of nozzles will be limited by the cooling speed of the extruded mass.*
- *The build and support materials are waxes with different melting points.*

(see Append. 1)

3.2.3 Ballistic Particle Manufacturing

Block diagram



3.2.4 Ballistic Particle Manufacturing

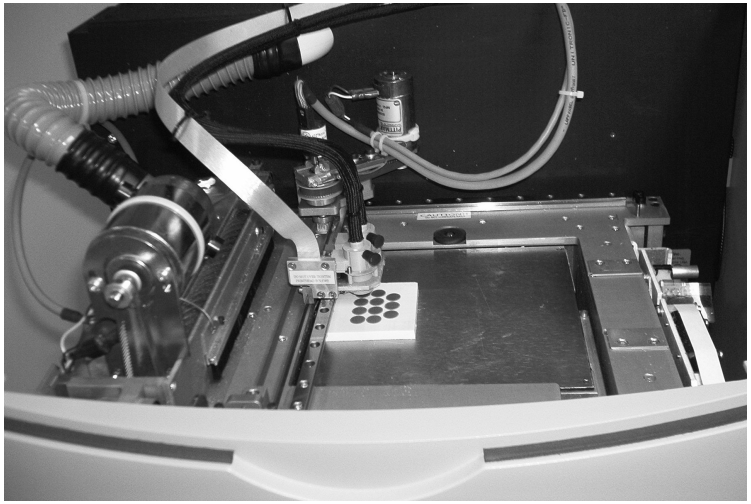
Equipments

3DSYSTEMS™	SOLIDSCAPE™

PROJET SERIE (1000, 1500, 3500, 5000)	3D WAX PRINTERS

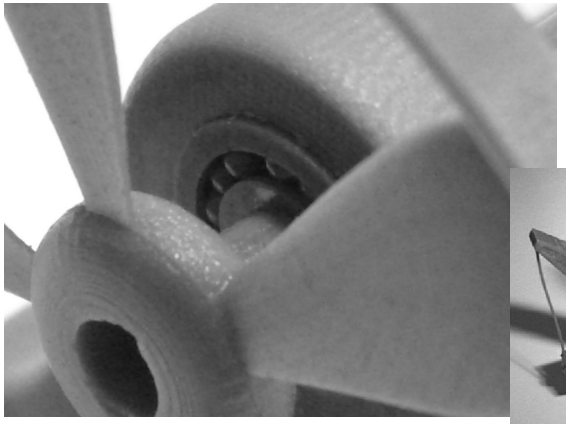
3.2.5 Ballistic Particle Manufacturing

Equipment (details of the SOLIDSCAPE ™ machine)

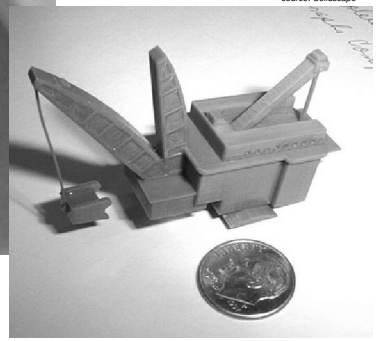


3.2.6 Ballistic Particle Manufacturing

Example of parts 1



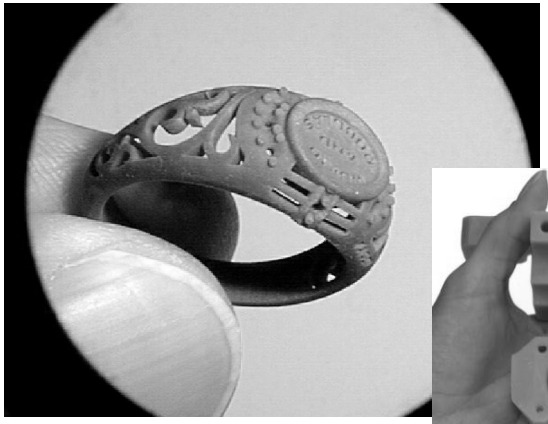
source: Solidscape™



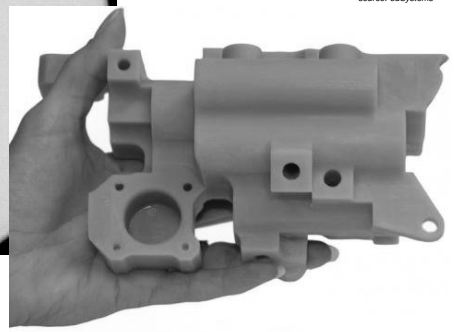
source: Solidscape™

3.2.7 Ballistic Particle Manufacturing

Example of parts 2



source: Solidscape™



source: 3dSystems™

3.2.8 Ballistic Particle Manufacturing, technical data

Mechanical properties of part (order of magnitude)

Material	*E, GPa*	R_m, *MPa*	ε_{rup}, %
Wax	-	-	-

Equipment (type, dimensions)

Build volume, mm^3		
from $120 \times 120 \times 120$	*to*	$300 \times 200 \times 200$

Performances

x-y resol., μm	***layer thickness***, μm	***build speed***, mm^3/s	***layering time***, *s*
$6 - 80$	*down to* 15	*MCR up to* 50	0 *or* $10 - 30$[1]

[1] A grinding operation can be applied between layers to ensure perfect flatness

3.2.9 Ballistic Particle Manufacturing

Companies

SOLIDSCAPE ™ *(part of* STRATASYS ™*)* 3DSYSTEMS ™*.*

Advantages (compared to FDM)

- *The materials are cheaper (pelets insteas fo normalized filaments).*
- *The manufacture is faster for an equivalent accuracy.*
- *Ideal for jewelry applications (lost patterns for the investment casting process).*
- *FDM-like plastic can also be processed by the* PROJET *machines developed by* 3DSYSTEMS ™*. The main issues are to maintain large quantities of molten material in the machine and to avoid blocking the printer head with the viscous polymer liquid.*

Disadvantages (compared to FDM)

- *Low mechanical properties of the part if the standard material (e.g. wax) is in use.*

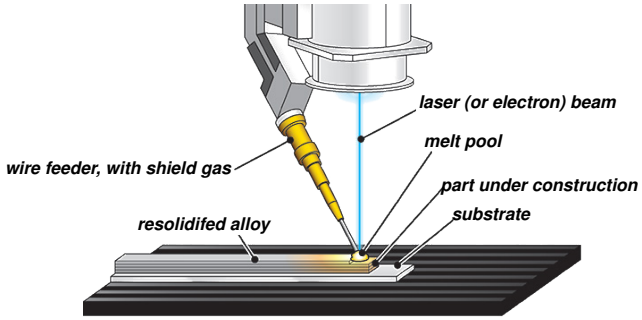
(see Append. 5)

"Laser Metal-Wire Deposition" (LMWD)

3.3.1 Laser Metal Wire Deposition

Principle

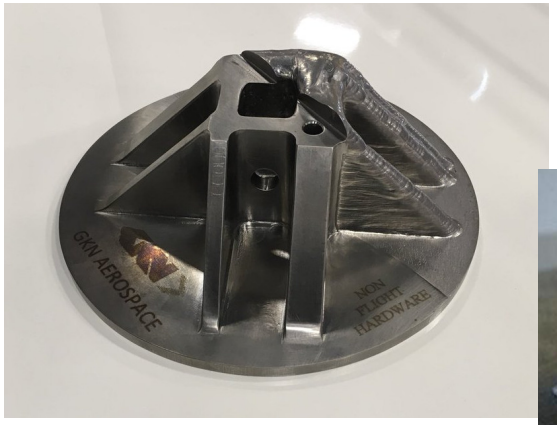
- *The LMWD process (**L**aser **M**etal **W**ire **D**eposition) is a metal version of FDM. The metallic wire is molten by a laser. There are **two types** of systems: systems with a laser integrated in the deposition nozzle (coaxial optical fiber), or systems with a laser moved externally and synchronized with the nozzle.*
- *The supports (if any) are build in the same material as the part itself (metal).*



- *The idea to melt the wire with a plasma torch is applied as well. The process is then called WAAM (**W**ire **A**rc **A**dditive **M**anufacturing).*

3.3.2 Laser Metal Wire Deposition

Example of parts 1



source: GKN™

source: Hackaday™

3.3.3 Laser Metal Wire Deposition

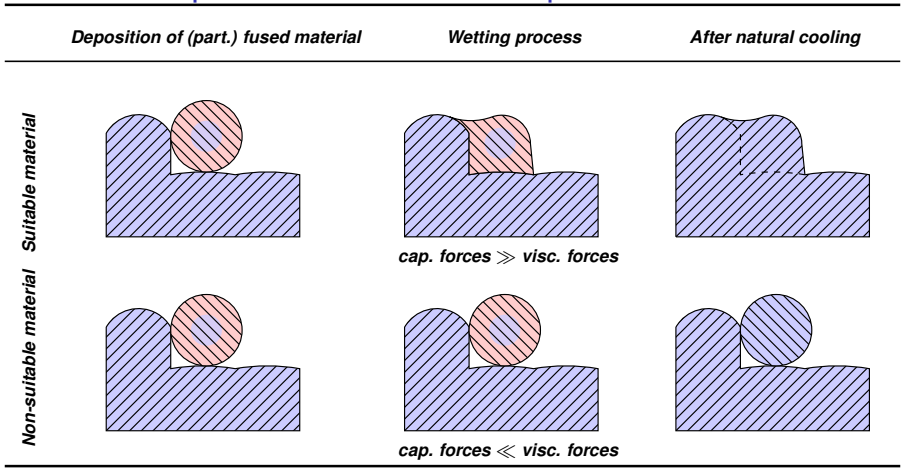
Example of parts 2

source: 3ders™

APPENDICES

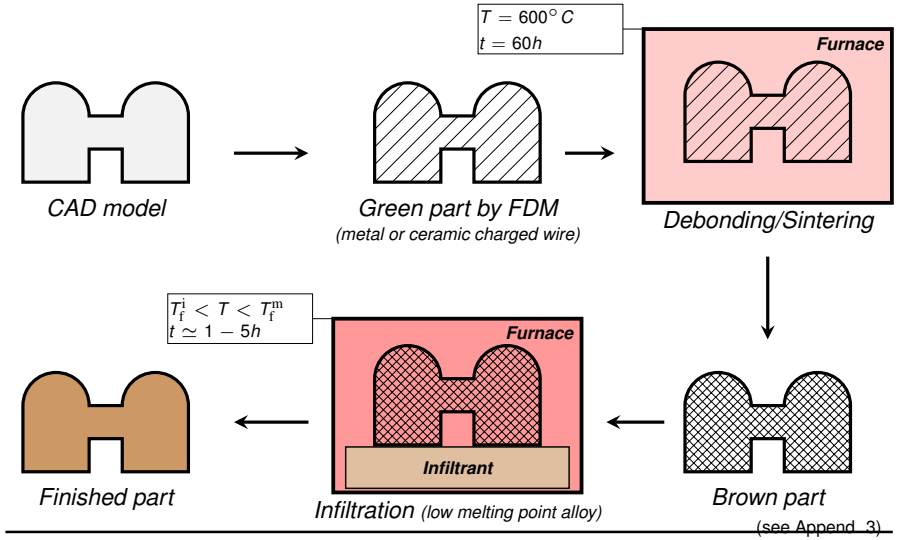
A 1: Liquid phase bonding

Different steps in the consolidation phase (view $\perp$ to deposition)



A 2: Metallic parts obtained by FDM

Indirect principle for producing metallic parts

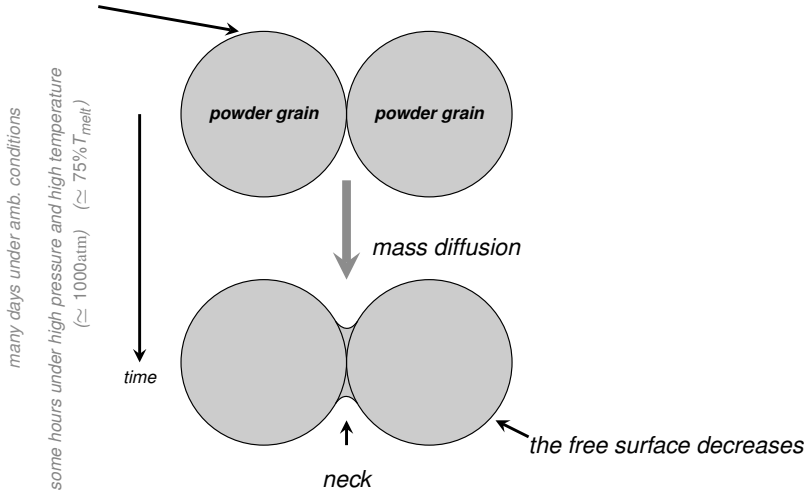


(see Append. 3)

A 3: Prod. processes: classical sintering

Physical principle of consolidation in classical sintering

free surfaces with high energy



A 4: Custom items (shoes) by FDM

Different types of shoes

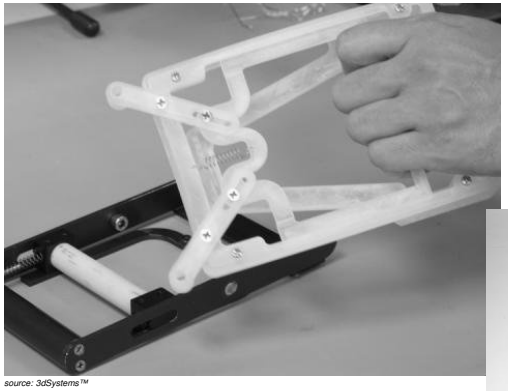
Traditional selection of extrusion process

$\Longrightarrow$ *good adequation of the resolution and of the materials with the application*

$\Longrightarrow$ *cheap and easy process*

A 5: Plastic part obtained by the BPM process

Example of parts



source: 3dSystems™

source: 3dSystems™