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CrossS3

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CENTEXBEL

VKC

Algemene introductie tot 3D-printen door extrusie van thermoplastisch materiaal – Korrels vs. Filamenten
Introduction générale à l'impression 3D par extrusion de matière thermoplastique – Pellets vs. Filaments

27/01/2026 – Workshop Tech4Fab - Cross S3

Overzicht / Aperçu

Wat is 3D-printen? / Qu'est-ce que l'impression 3D?

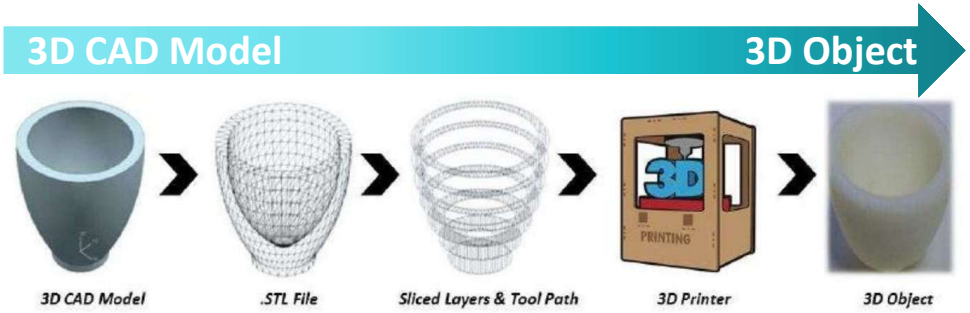
Korrels vs. filamenten als inputmateriaal / Granulés vs. filaments comme matériaux d'entrée

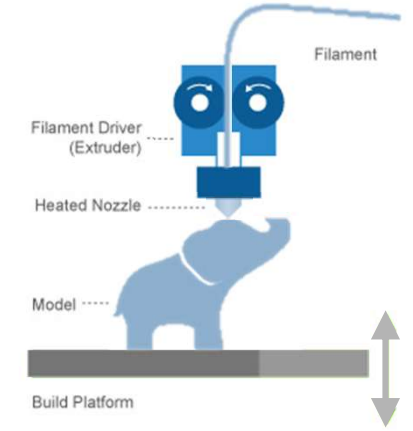
3D-printen bij Centexbel / Impression 3D au CTB

Wat is 3D-printen? / Qu'est-ce que l'impression 3D?

3D-printen is een familie van technieken die het mogelijk maakt om een object te vervaardigen op basis van 3D-modeldata, door middel van laag-op-laag afzetting.

L'impression 3D est un ensemble de techniques qui permettent de créer un objet à partir d'un modèle 3D via un dépôt couche par couche.



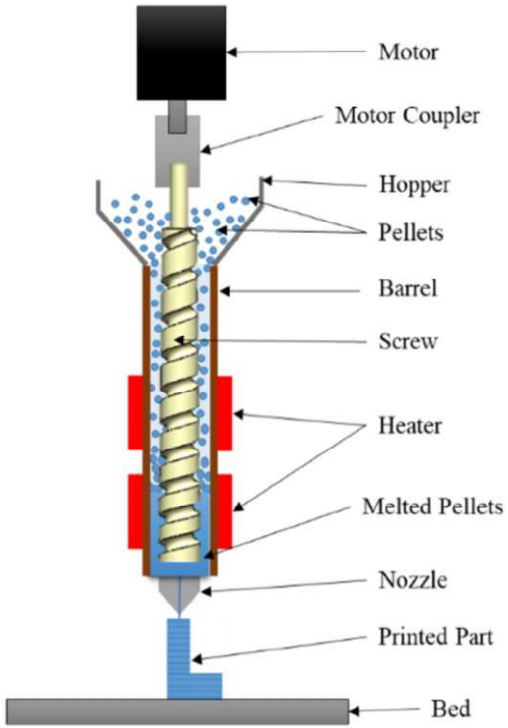


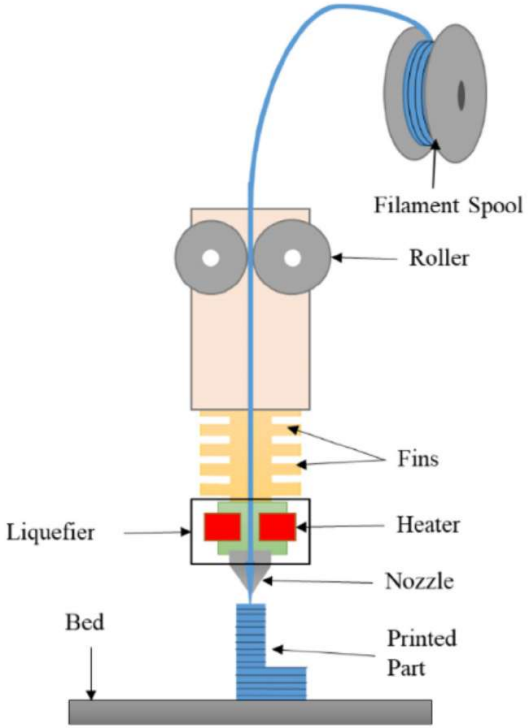
Fused Deposition Modeling (FDM)

Het materiaal wordt laag per laag geëxtrudeerd op het platform, waar de lagen met elkaar versmelten en stollen tot het gewenste 3D-object.

Le matériau est extrudé couche par couche sur la plateforme, où les couches fusionnent et se solidifient pour créer l'objet 3D désiré.

Korrel- en filamentprinters / Imprimantes à granulés et à filaments



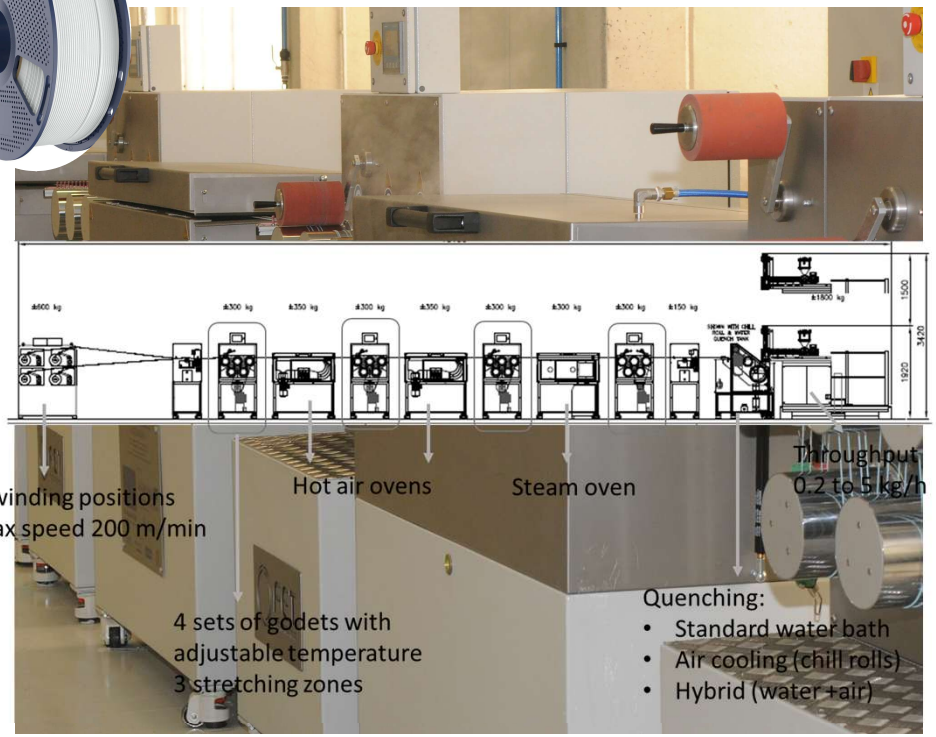


Gupta, A. K., & Taufik, M. (2021). *Materials Today: Proceedings, 47*, 5177–5184

Korrel vs. filament 3D-printers / Imprimantes 3D à granulés vs. à filaments

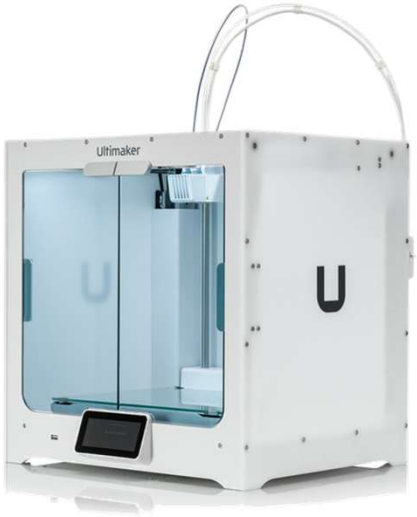
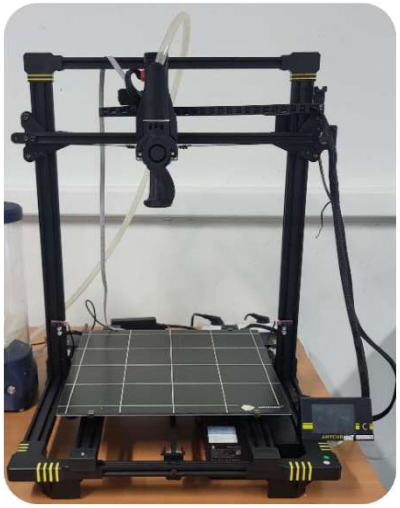
Korrel 3D-printers / Imprimantes 3D à granulés		Filament 3D-printers / Imprimantes 3D à filaments	
✓	✗	✓	✗
Direct gebruik van korrels / Utilisation directe des granulés	Minder gestandaardiseerd / Moins standardisé	Grote toegankelijkheid / Large accessibilité	Beperkte hoeveelheid vulstoffen mogelijk / Teneur en charges limitée
Hoge tolerantie voor vulstoffen / Haute tolérance aux charges	Hogere thermische belasting / Charge thermique plus élevée	Minder thermische verblijftijd / Temps de séjour thermique réduit	Afhankelijk van filamentkwaliteit / Dépendance à la qualité du filament
Hoge afzetsnelheid / Taux de dépôt élevé		Goed ingeburgerde technologie / Technologie bien établie	Beperkte tolerantie voor gerecycleerde materialen / Tolérance limitée aux matériaux recyclés
Tolerantie voor abrasieve vulstoffen / Bonne tolérance aux charges abrasives			Mogelijke brosheid van filament (vooral als gevuld) / Fragilité potentielle du filament (surtout les chargés)

Productie van het inputmateriaal @CTB / Fabrication du matériau d'entrée @CTB

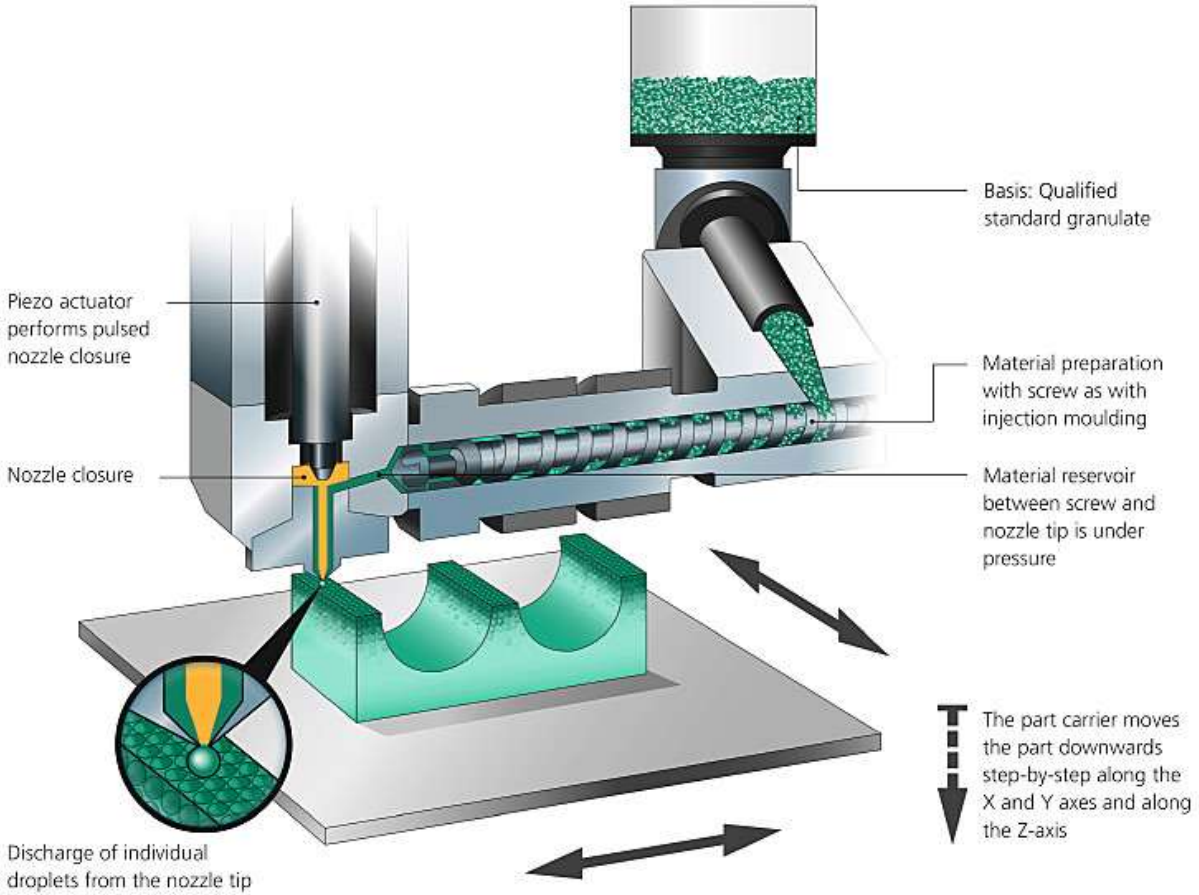


Extrusie-gebaseerde 3D-printers @CTB/ Imprimantes 3D basées sur l'extrusion @CTB

De technieken zijn geschikt voor thermoplastische polymeren / Les techniques conviennent aux polymères thermoplastiques

Filamenten / Filaments	Korrels / Granulés		
			
Ultimaker S5	Anycubic Chiron	Tumaker	Arburg Plastic Freeformer

‘Freeforming’ technologie



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Bedankt! / Merci beaucoup!

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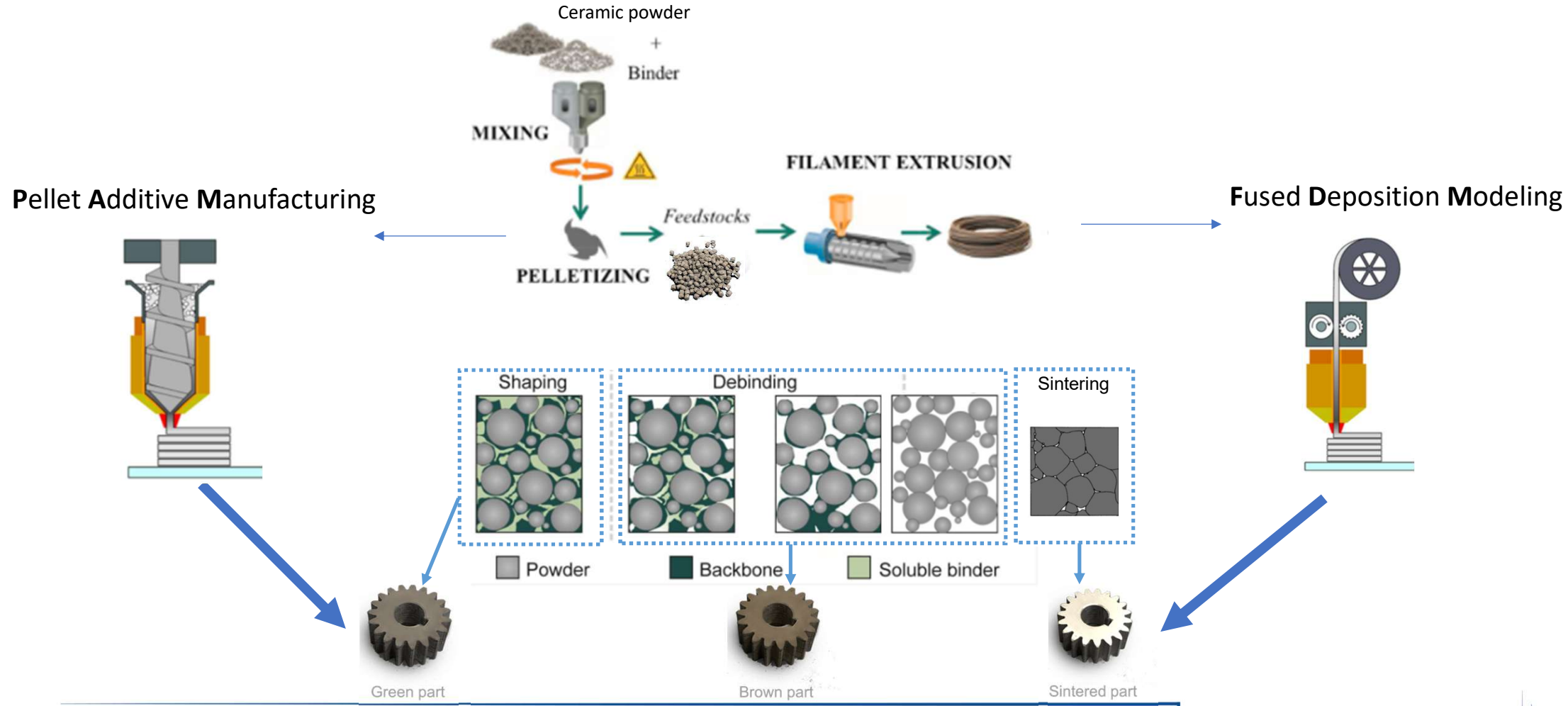
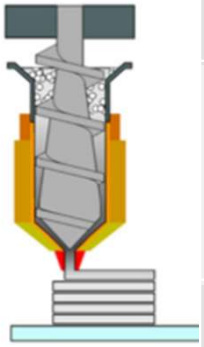
La fabrication additive par extrusion thermoplastique
Additieve vervaardiging via thermoplastische extrusie
-
Applications aux Céramiques / Toepassingenop Keramiek

Principe de l'extrusion de thermoplastiques chargés
Principe van de extrusie van gevulde thermoplasten



Avantanges et inconvenients – Cas spécifiques des céramiques
Voordelen en nadelen - Specifieke gevallen van keramieken

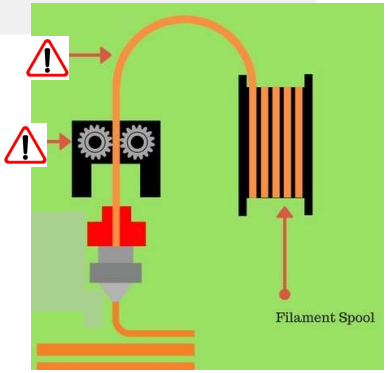
PAM



Pellet
Large gamme de pellets industriels (CIM) disponibles Breed assortiment industriële pellets (CIM) beschikbaar
Vitesses de dépôt élevées et volume d'impression important Hoge afdruksnelheden en een groot afdrukvolume
Taux de charge élevé Hoge belastingsgraad
€€

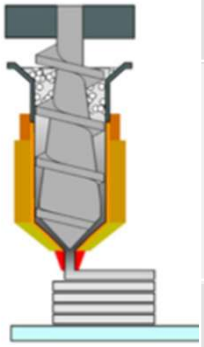
Filament
Offrir une grande précision et complexité Bieden een grotere precisie en complexiteit
Large gamme d'équipement (FDM) Breed assortiment aan apparatuur (FDM)
Filaments chargés sont fragiles Geladen filamenten zijn kwetsbaar
€€€€

FDM



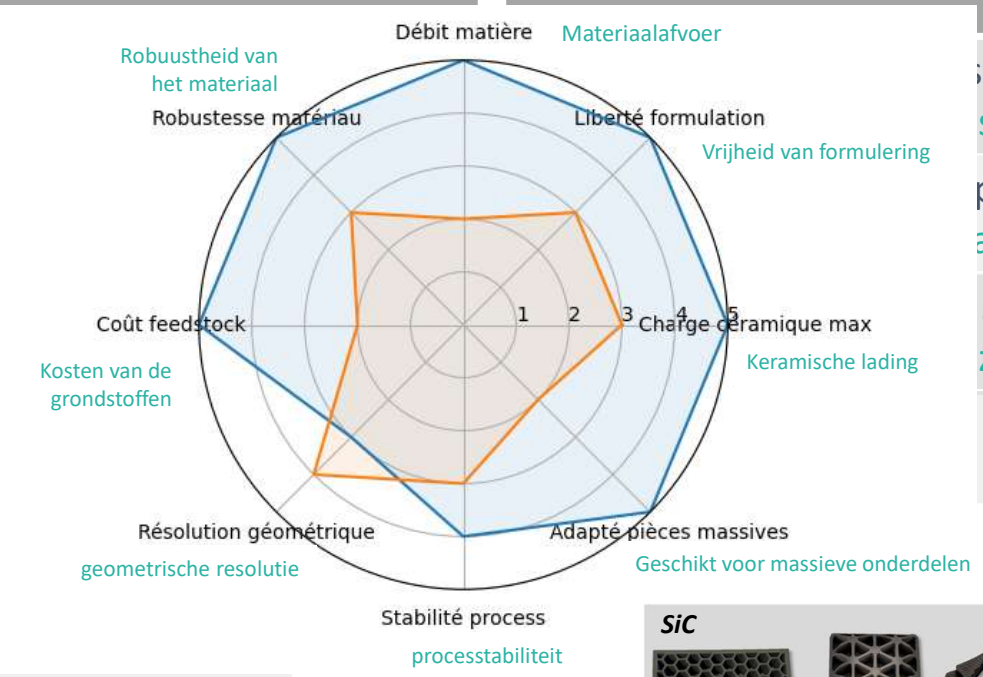
Avantanges et inconvenients – Cas spécifiques des céramiques
Voordelen en nadelen - Specifieke gevallen van keramieken

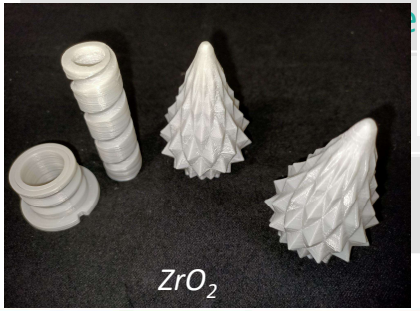
PAM

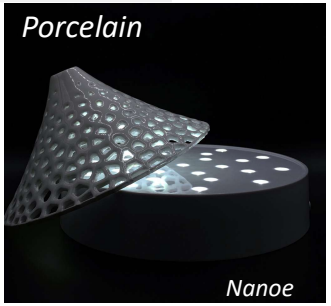


FDM

Pellet	Filament
Large gamme de p… disp… Breed assortiment … bes…	…sion et complexité …sie en complexiteit
Vitesses de dép… d'impress… Hoge afdruksne… afdru…	…pement (FDM) …apparatuur (FDM)
Taux de …	… sont fragiles … zijn kwetsbaar
€€	







https://doi.org/10.1016/j.jeurceramsoc.2025.117229

Principaux challenges de la fabrication additive par extrusion
Belangrijkste uitdagingen van additieve vervaardiging door extrusie.

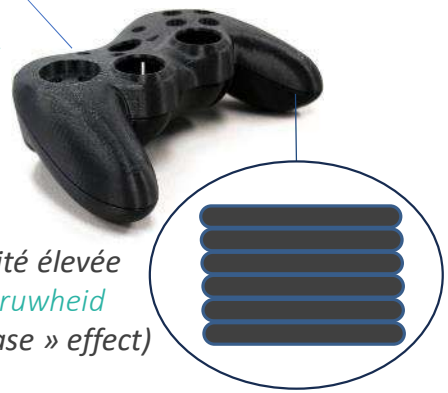
❑ **Comment obtenir des pièces de densité élevé? /** Hoe verkrijgt men onderdelen met een hoge dichtheid?

- Obtenir des pièces sans défaut (délamination, défauts entre les cordons, fissures, porosité) est une tâche délicate !
  Het verkrijgen van foutloze stukken (zonder delaminatie, defecten tussen de strengen, scheuren en porositeit) is een delicate opgav

❑ **Comment améliorer la finition de surface ? /** Hoe kan men de oppervlakte-afwerking verbeteren?

Surfaces internes en contre-dépouille ou inaccessibles pour la post-finition

Interne oppervlakken met onderuitsparingen of die onbereikbaar zijn voor nabehandeling



Rugosité élevée
Hoge ruwheid
(« staircase » effect)

- Finition de surface << pièces moulées par injection
  Oppervlakte-afwerking << spuitgegote onderdelen

- Amélioration de la qualité de surface en utilisant des buses plus fines -> augmentation du temps d'impression et du risque de défauts
  Verbetering van de oppervlaktekwaliteit door gebruik van fijnere nozzles → toename van de printtijd en van het risico op defecten

Cas d'étude d'une céramique PAM

Casestudy van een keramiek PAM

- Black Zirconia (INMAFLOW K2015 – INMATEC Technologies Gmbh)

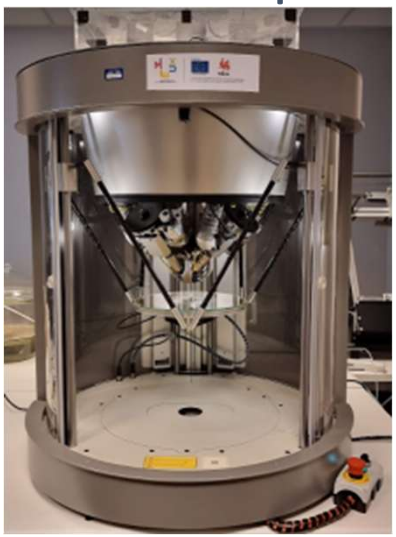
Bonnes propriétés d'écoulement attendues – convient à l'extrusion AM

Goede verwachte vloei-eigenschappen – geschikt voor AM-extrusie

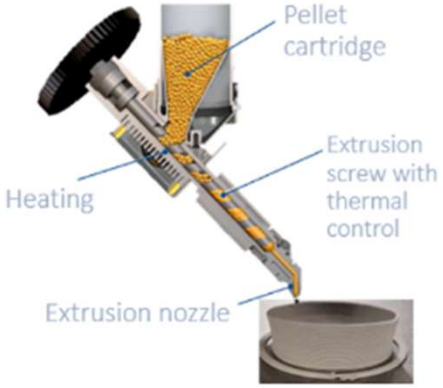
Feedstock	ZrO_2, 94.5%, Y_2O_3 partially stabilized TZ-black (Tosoh Corp)
Sintered density	6.00 g/cm³
Shrinkage	17%
Binder	Polyamide based
Debinding	2 steps : - Aceton bath - Thermal debinding up to 325°C
Sintering	1400°C under air

Shaping processing (CIM)	
Mould temperature	15 – 30 °C
Heating zone temperature	110 °C
Nozzle temperature	150 °C

PAM : Optimisation de l'impression / Optimalisatie van het printen



Pollen AM- PAM series C



- Huge parameter space:
  - Extrusion settings
    - Temperature control: screw, nozzle, building plate, fan cooling.
    - Adjustment of printing speed/material flow
    - Nozzle diameter (0.4, 0.6, 0.8, 1.0, 1.2, 1.8 mm)
  - Layer filling
    - Lines, gyroïds, concentric…
    - Interlayer spacing, interfilament spacing

Réglages préliminaires pour l'impression
Voorafgaande instellingen voor het printen

- 1 mm nozzle diameter
- Nozzle temperature: 150°C
- Extruder temperature: 110°C
- Cold point temperature: 43°C
- Building plate temperature: 35°C

Profil de température de l'extrudeur
Temperatuurprofiel van de extruder

- « Extruder flow »: 35 %
- Printing speed: 20 mm/s

Paramètres de débit
Debietparameters

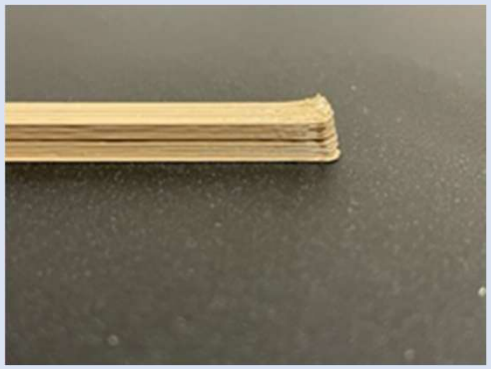
- Layer thickness: 1/3 nozzle diameter
- Overlapping= 1/4 * nozzle diameter
- Line filling
- Infill density: 100%

Stratégie d'impression
Printstrategie

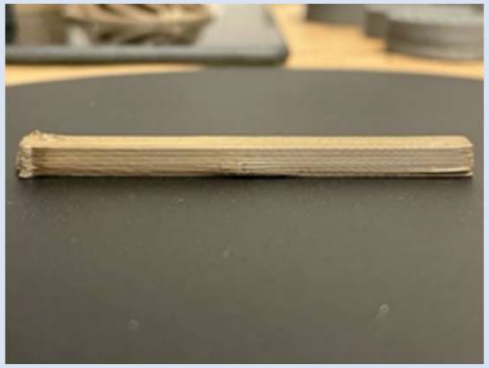
- Test bars: 60 mm x 6.5 mm x 4.7mm

Pièces imprimées
Geprinte onderdelen

Première impression… et quelques défauts
Eerste print… en enkele defecten



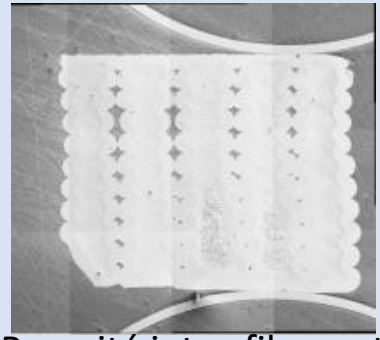
Délamination
Delaminatie



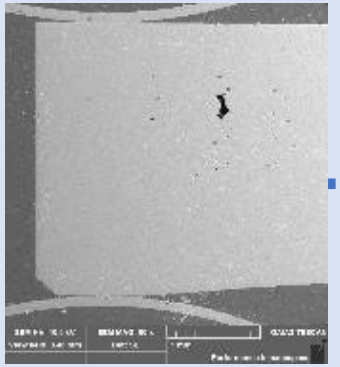
faible adhésion des pièces sur le plateau de fabrication
Zwakke hechting van de onderdelen op het bouwplatform

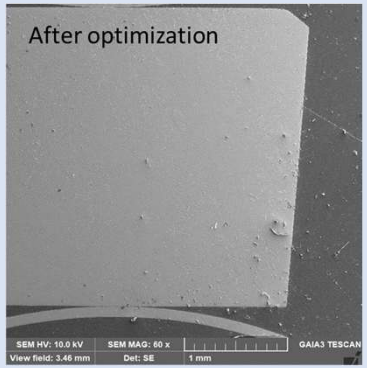
Warping

Trous
Gaten



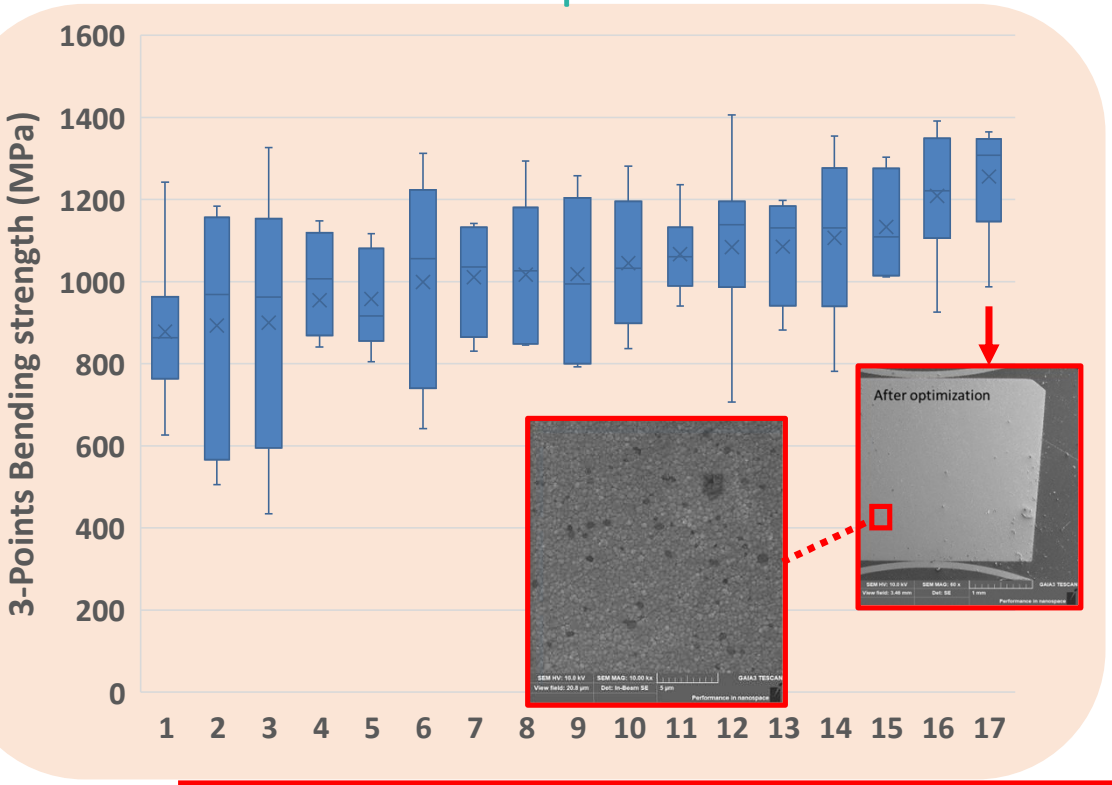
Porosité inter-filament
Inter-filament porositeit

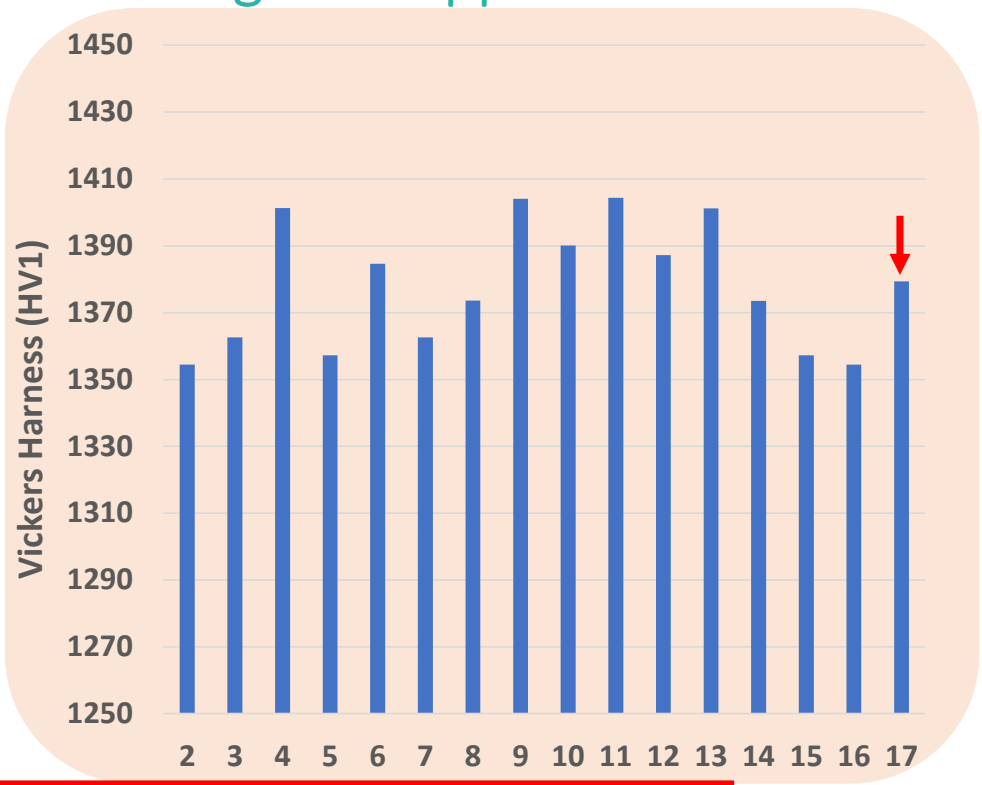




Impression et propriétés mécaniques améliorés

Verbeterde printkwaliteit en mechanische eigenschappen



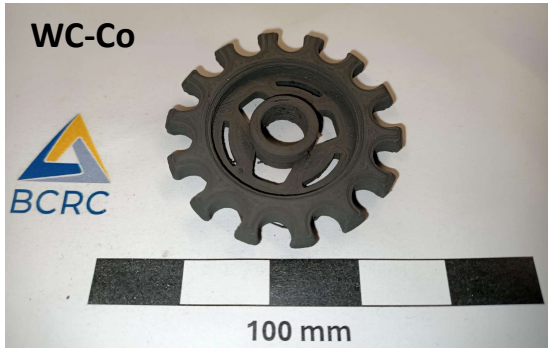


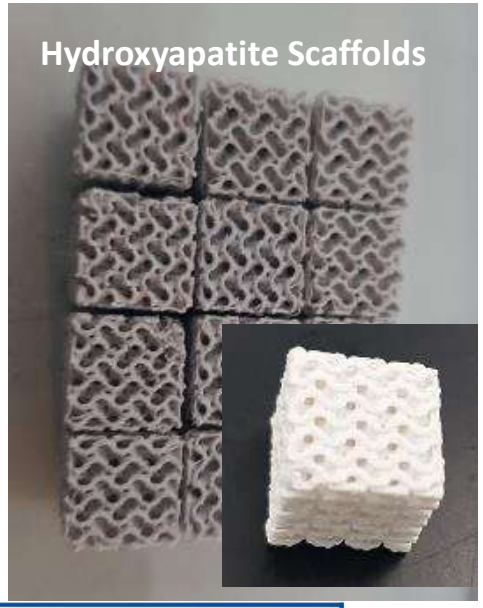
Layer height (mm)	Infill (%)	Nozzle T (°C)	Flow (%)	Relative density (%)	σ_f (MPa)	Vickers hardness (HV1)
0.34	100	165	43	99.8	**1256 ± 137**	**1379**

Référence / Referentie ZrO2 TZ-black (Tosoh Corp) σ_f= 1200 MPa - 1250 HV10 (density 6.05g/cm^3)

Quelques exemples… zircone
Enkele voorbeelden… zirkonia

Quelques exemples… autres matériaux
Enkele voorbeelden… andere materialen





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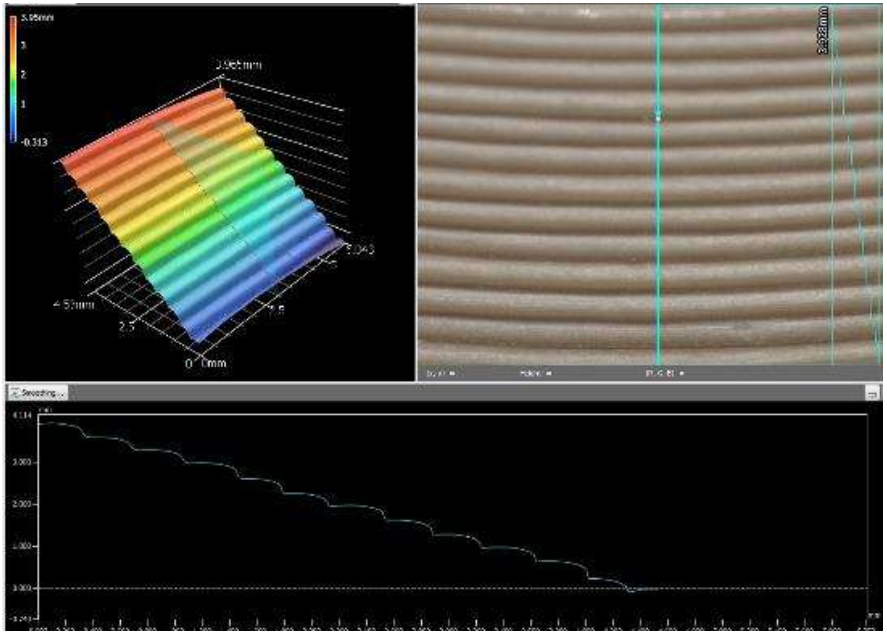

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  Interne oppervlakken met onderuitsparingen of die onbereikbaar zijn voor nabehandeling

Hybridation du procédé PAM / FDM
Hybridisatie van het PAM / FDM-proces

- L'hybridation combine les avantages de la **fabrication additive et de l'usinage,** pour l'amélioration du fini de surface et la qualité globale des pièces produites.

De hybridisatie combineert de voordelen van **additieve vervaardiging en verspaning**, om de oppervlakteafwerking en de globale kwaliteit van de geproduceerde onderdelen te verbeteren.

- Pourquoi l'hybridation PAM/FDM est-elle pertinente ?

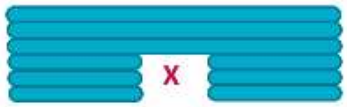
Waarom is de hybridisatie van PAM en FDM relevant?

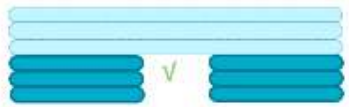
- Le matériau extrudé se solidifie rapidement
- Le matériau imprimé est constitué d'un thermoplastique facile à usiner
- Équipement CNC compatible et peu coûteux
- Les résidus d'usinage peuvent être facilement recyclés

- Het geëxtrudeerde materiaal stolt snel
- Het geprinte materiaal bestaat uit een gemakkelijk te bewerken thermoplast
- Compatibele en goedkope CNC apparatuur
- Bewerkingsresten kunnen gemakkelijk worden gerecycled

Post-usinage -> certaines ne sont plus accessibles

Nabewerking -> sommige zijn niet meer toegankelijk

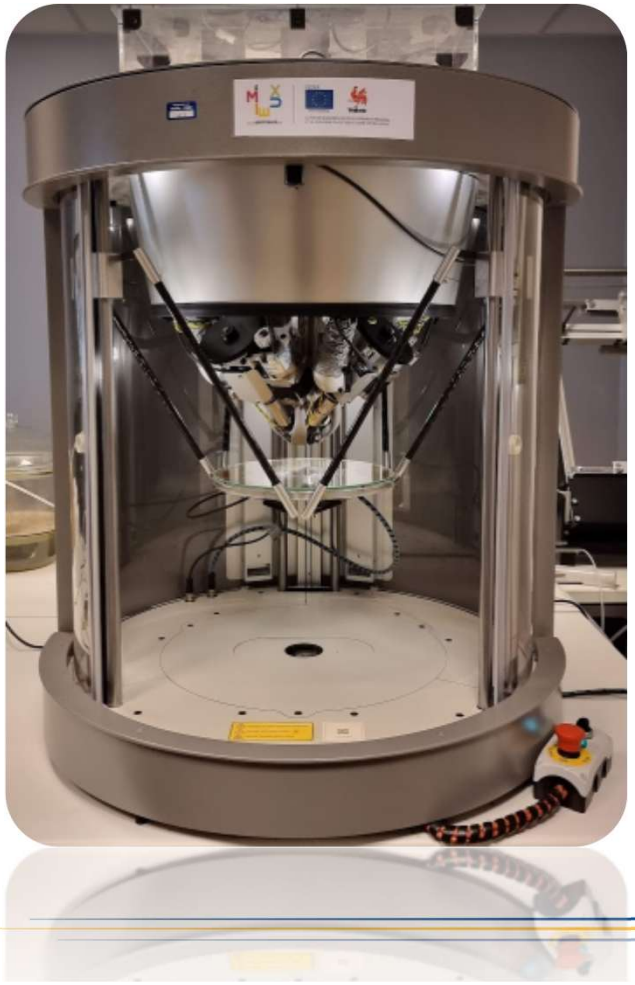


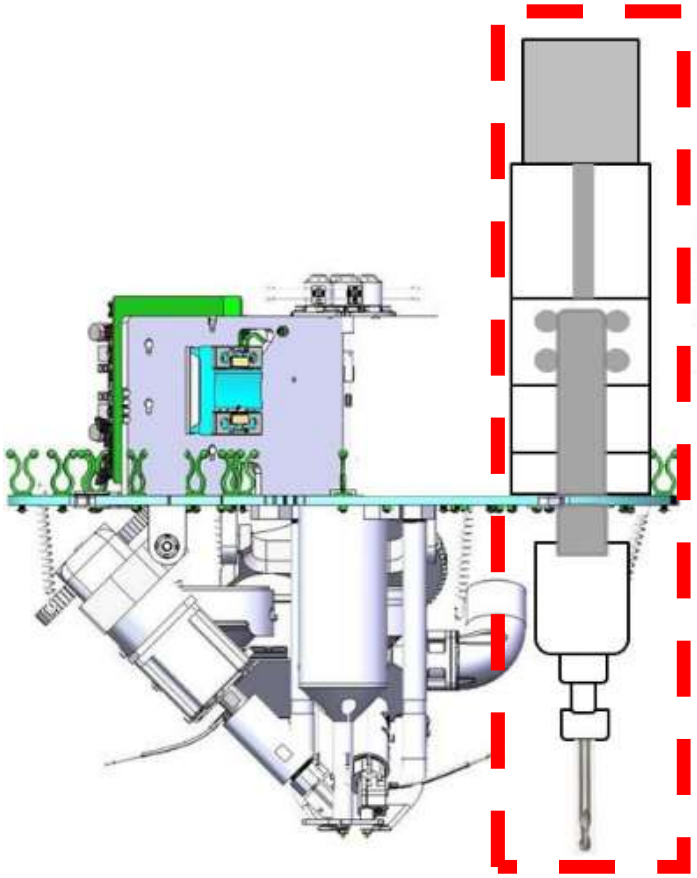


Procédé séquentiel -> presque que toutes les zones sont accesibles

Sequentiële print-> freesbewerking -> vrijwel alle gebieden zijn toegankelijk

Hybridation du procédé PAM
Hybridisatie van het PAM-proces





Spindle:
- Max speed: 50 000 rpm
- Max torque: 6 N.cm

Hybridation du procédé PAM
Hybridisatie van het PAM-proces

Objectif : Garantir une bonne communication entre les différents composants de la machine
Doel: Een goede communicatie tussen de verschillende onderdelen van de machine garanderen

1) Créer un post-processeur adapté / Maak een geschikte postprocessor aan
-> adapter gcode de l'outil de coupe avec le PAM-gcode / Gcode van het snijgereedschap aanpassen met PAM-gcode
-> XYZ zero offsets, désactiver l'impression … / XYZ-nulafwijkingen, afdrukken uitschakelen...

2) Définir les parties imprimées et usinées / De geprinte en bewerkte onderdelen definiëren

3) Sélectionner des stratégies d'impression et d'usinage adaptées / Selecteer geschikte print- en bewerkingsstrategieën

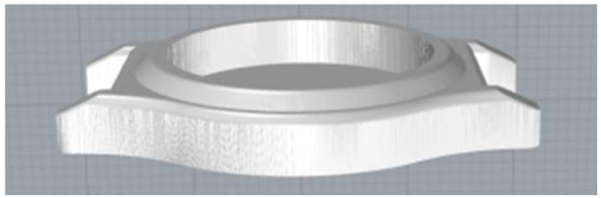
4) Test de différents types de pièces / Testen van verschillende soorten onderdelen
- Finition d'une forme complexe (cycle unique d'impression/fraisage)
  Afwerking van een complexe vorm (enkele cyclus van printen/frezen)

- Fabrication hybride complexe (cycle multiple d'impression/fraisage)
  Complexe hybride productie (enkele print-/freescyclus)

Hybridation du procédé PAM

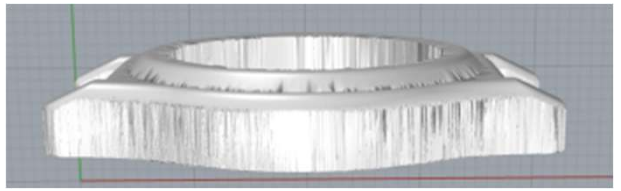
Hybridisatie van het PAM-proces

CAD file



0.6 mm offset

Over-sized CAD file



Boîtier de montre en zircone imprimé avec une buse de 400 µm

Zirkoniumoxide horlogekast bedrukt met een spuitmond van 400 µm

Printing time ~ 3 hours

Boîtier de montre imprimé avec une buse de 1mm

Bedrukt horlogekastje met een spuitmond van 1 mm ~**30 minuten**

Boîtier de montre fraisé avec une fraise boule de 2,5 mm

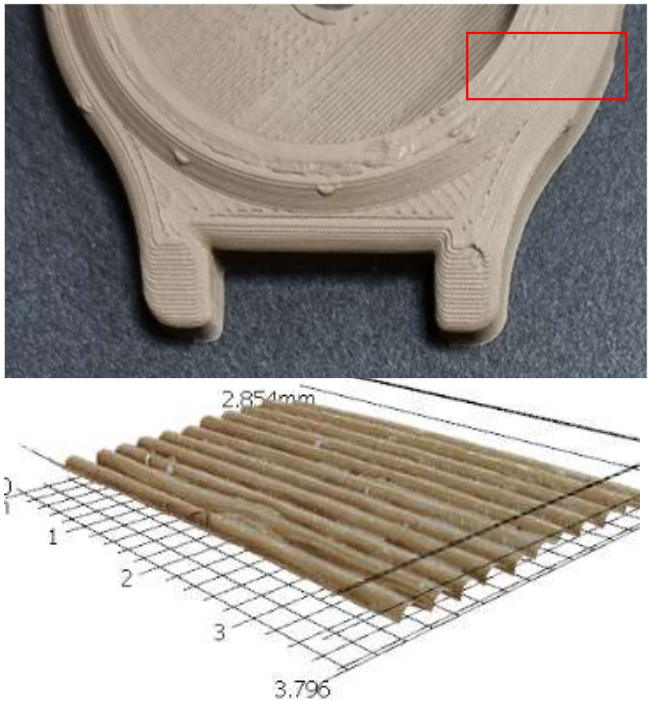
Horlogekast gefreesd met een 2,5 mm kogelfrees ~ **30 minuten**

Manufacturing time ~ 1 hour

Hybridation du procédé PAM
Hybridisatie van het PAM-proces

Fini de surface imprimé avec une buse de 0,4 mm

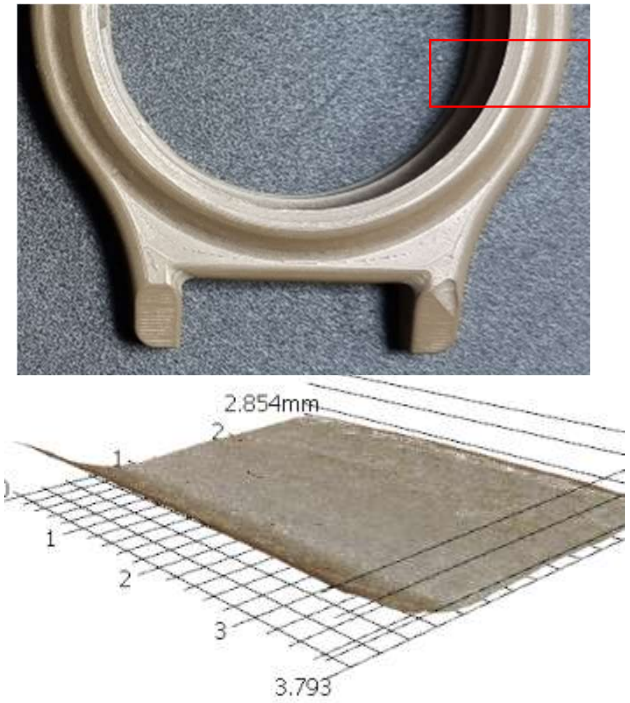
Gedrukt oppervlak met een spuitmond van 0,4 mm



No.	Measurement name	Measured value	Unit
1	Ra	0.015	mm
2	Rz	0.056	mm

Fini de surface après un usinage

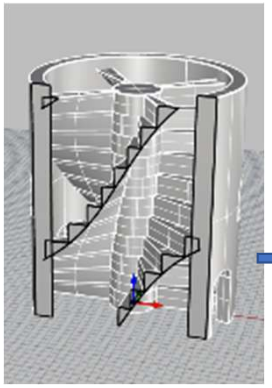
Oppervlakteafwerking na bewerking



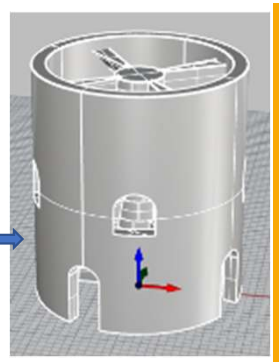
No.	Measurement name	Measured value	Unit
1	Ra	0.001	mm
2	Rz	0.003	mm

Hybridation du procédé PAM / Hybridisatie van het PAM-proces

Additive part calculation

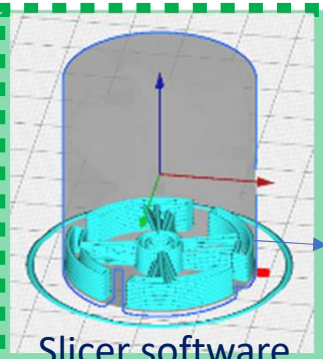


Original file "A tower with a double helix staircase"



Enlarged model

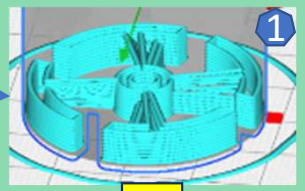
home made post-processor



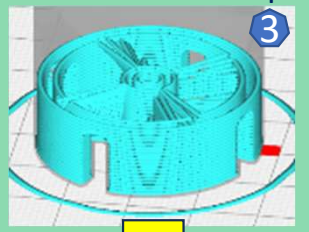
Slicer software

Sliced model

Toolpath calculation at the first step



Toolpath calculation at the second step



print on 6 mm thickness

First step milling

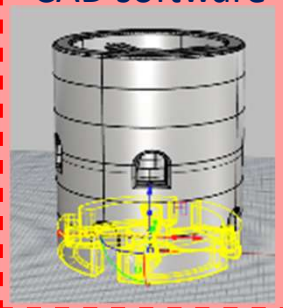
Print 6mm more

Second step milling

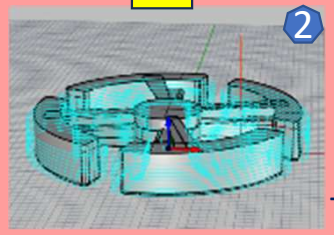
Timeline

Subtractive part calculation

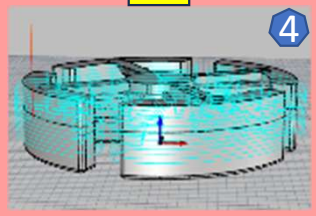
CAD software



Toolpath calculation at the first step

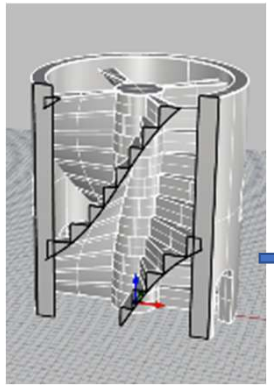


Toolpath calculation at the second step

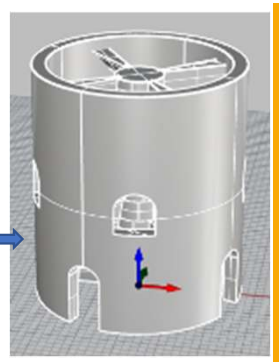


Hybridation du procédé PAM / Hybridisatie van het PAM-proces

Additive part calculation



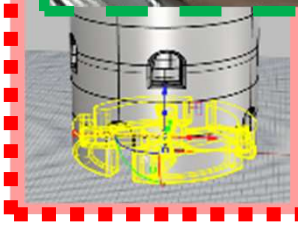
Original file "A tower with a double helix staircase"

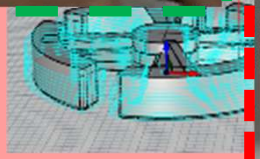


Enlarged model

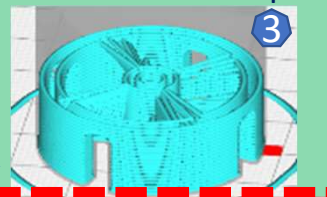
home made post-processor

Toolpath calculation at the first step





Toolpath calculation at the second step

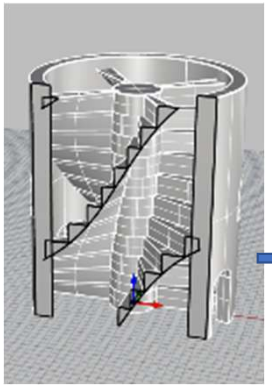


Subtractive part calculation

*Ref: Joris ALBOS , Umons-Génie MECA

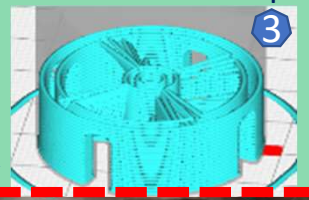
Hybridation du procédé PAM / Hybridisatie van het PAM-proces

Additive p

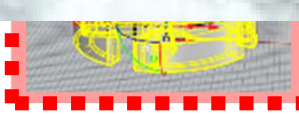


Original file "A tower with a double helix staircase”

Toolpath calculation at the second step



Subtractive part calculation



Toolpath calc… at the first step

Conclusion et perspectives / Conclusie en vooruitzichten

✓ Le procédé PAM permet d'obtenir des pièces avec des propriétés mécaniques proches de celles obtenu par CIM

✓ Met het PAM-proces kunnen onderdelen worden vervaardigd met mechanische eigenschappen die vergelijkbaar zijn met die van CIM-onderdelen

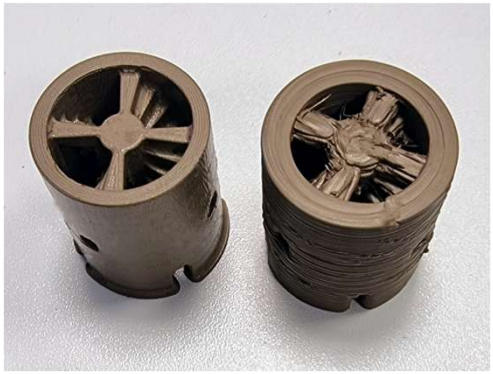
$$ZrO_2\ \sigma_{r3PB} = 1256 +/- 137\ MPa$$

✓ Une rugosité pouvant atteindre 1 µm peut être obtenue à l'état cru sur des pièces post-traitées in situ dans la machine PAM.

✓ Een ruwheid tot 1 µm kan worden bereikt in onbewerkte toestand op onderdelen die in situ in de PAM-machine zijn nabehandeld.

$$R_a = 1\mu m$$

✓ Un procédé hybride est en cours de développement pour fabriquer des formes complexes avec des surfaces intérieures et extérieures finies.



✓ Er wordt momenteel een hybride proces ontwikkeld om complexe vormen met afgewerkte binnen- en buitenoppervlakken te vervaardigen.

Thank you for your attention !

The European Regional Development Fund (ERDF) and Wallonia, are gratefully acknowledged for their financial support to these research projects CERAMTOP, CERAMPLUS “Iawatha” in the frame of the “Transition programme” and EXTRUwall-Wi^{3}ning.

Win2Wal HYPROPAM (Convention 2110084)

Pierre Grimaud, Ceramorph project

Belgian Ceramic Research Centre (BCRC)
Avenue Gouverneur Cornez, 4 – B-7000 Mons, BELGIUM
Tel: +32 (0) 65 40 34 34 – Fax: +32 (0) 65 40 34 60
www.bcrc.be

LaM CU3E
Laboratoire de mécanique, multiphysique, multiéchelle

Interreg
Cofinancé par l'Union Européenne
Medegefinancierd door de Europese Unie
France - Wallonie - Vlaanderen

CrossS3
TECH4FAB-Cross S3

Mise au point et développement d'un procédé de Fabrication Additive Métallique accessible au plus grand nombre

Afstelling en ontwikkeling van een voor een breed publiek toegankelijke metalen additieve fabricagemethode

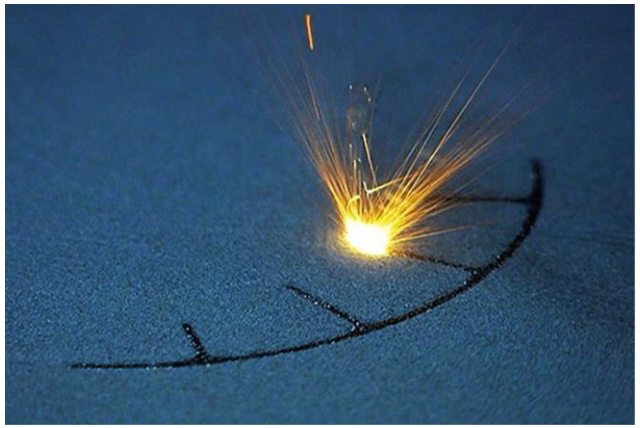
Sophie Badin, **Jean-François Witz, Vincent Magnier, Delphine Auzene, Denis Najjar**

WorkShop Tech4Fab, BCRC, Mons, 27/01/26

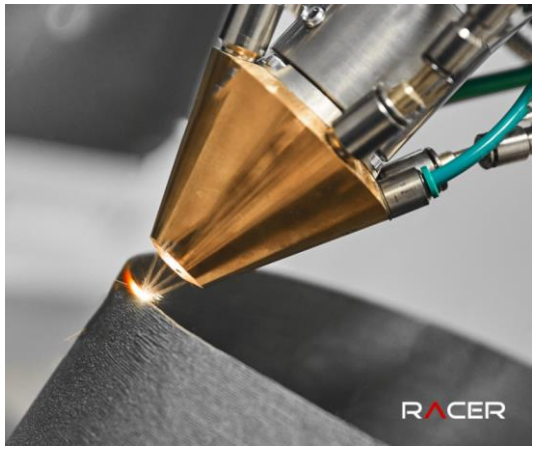
CRITT MATÉRIAUX INNOVATION
Université de Lille
cnrs
centralelille

État de l'art de la fabrication additive métallique (FAM)
Stand van de techniek van metaal-additieve fabricage (FAM)

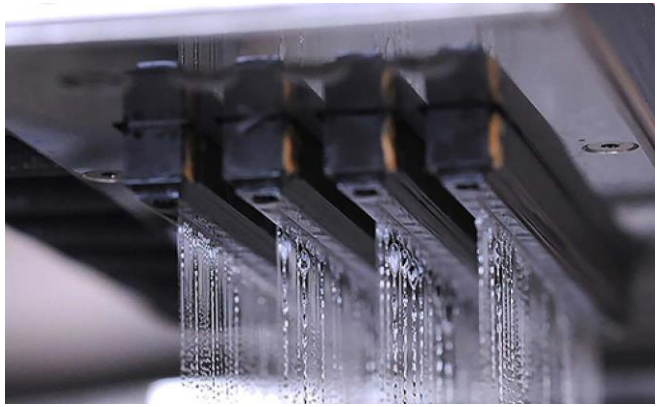
Powder Bed Fusion (PBF)



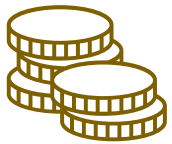
Direct Energy Deposition (DED)



Binder Jetting (BJ)



Poudres libres | Vrije poeders



[200k€ - 1000k€]

pollution machine

Machinevervuiling

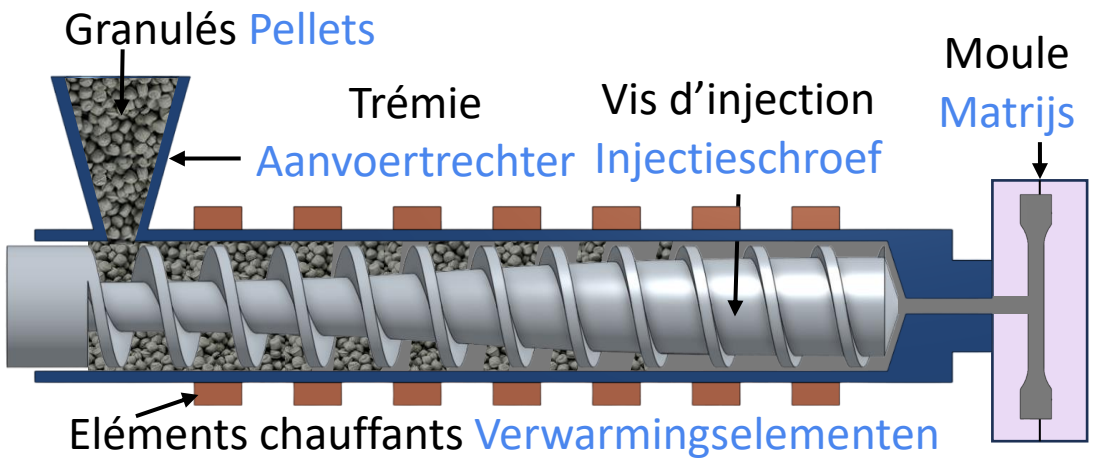
Émergence nouvelles technologies inspirées du **Metal Injection Molding** (MIM)

Opkomst van nieuwe technologieën geïnspireerd op **Metal Injection Molding** (MIM)

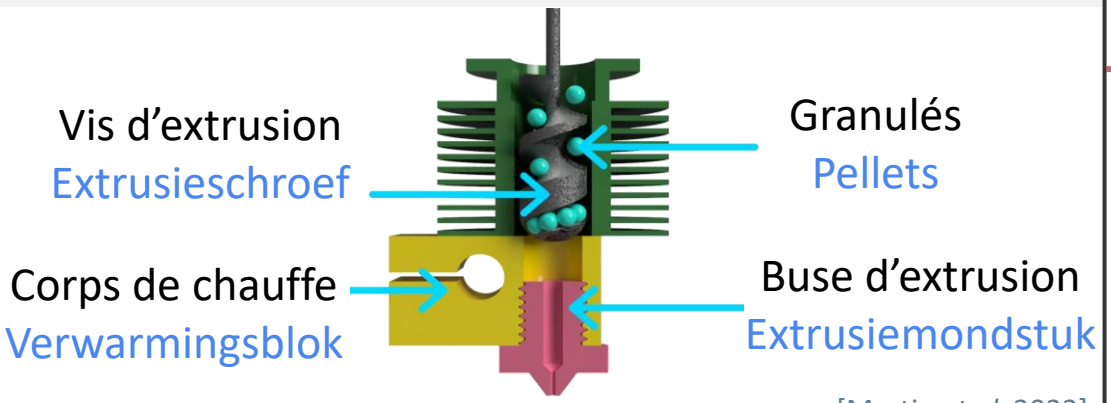
Images : Irepa Laser, Racer Machinery International, ExOne

Présentation des procédés MIM et MIM-like
Presentatie van de MIM- en MIM-achtige processen

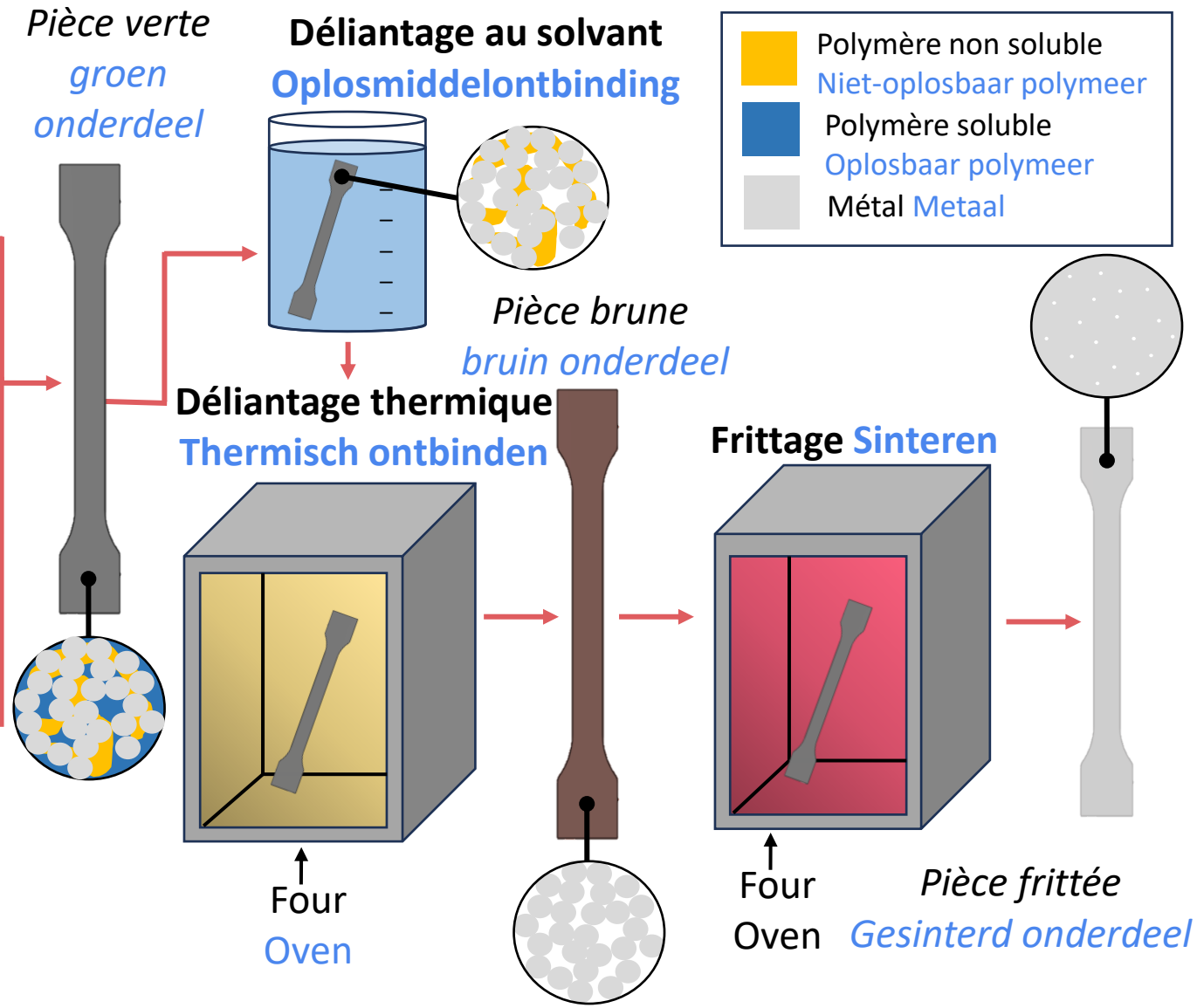
Metal Injection Molding (MIM) – Injection
Metal Injection Molding (MIM) – Injectie



Impression 3D MIM-like – Extrusion
MIM-achtige 3D-printing – Extrusie



[Martin *et al.* 2022]



Plus values du procédé MIM-like
Meerwaarde van het MIM-achtige procedé

Économies sur machine Besparingen op machines

+

Suppression moules Afschaffing van matrijzen

	Powder Bed Fusion	Direct Energy Deposition	Binder Jetting	MIM	MIM - like
Investissements initiaux **Initiële investeringen**	€€€€	€€€€	€€€	€€€	€
Coût des matériaux et de fonctionnement **Materiaal- en bedrijfskosten**	€€€€	€€€	€€€€	€	€
Diversité des matériaux **Materiaaldifferentiatie**	++	++	++	+++	+++

Économies sur machine et matériaux Besparingen op machines en materialen

✓ **MIM-like → Imprimantes de « bureau » Desktop-3D-printers**

Sécurité : Poudres enrobées Veiligheid: omhulde poeders

Sources : All3DP, A3DM Magazine, Primante 3D (Pollen)

État du marché du procédé MIM-like
Marktpositie van het MIM-achtige proces

MarkForged
~ 200 k€

Desktop Metal
~ 200 k€

✗

✓ Utilisation simple ✓

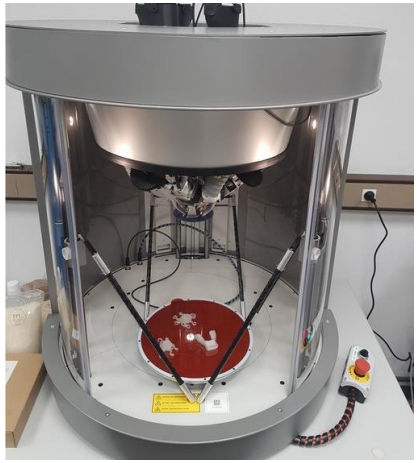
Coûts élevés Hoge kosten

Paramètres non accessibles (imprimante et four)
Niet-toegankelijke parameters (printer en oven)

✗

Ensemble imprimante + solution déliantage/frittage
Printer + ontbindings- en sinteroplossing

Pollen ~ 80 k€



Imprimante vendue seule
Printer los verkocht

✓ Paramètres accessibles ✓
Toegankelijke parameters

✗

Utilisation laborieuse Moeizaam gebruik

Nécessite sous-traitance pour le frittage
Sinteren vereist uitbesteding

✗

Four industriel ~ 400 k€
Industriële sinteroven ~ 400 k€

Contexte
Context

Interreg France-Wallonie-Vlaanderen — UNION EUROPÉENNE EUROPESE UNIE

FabricAr3v

Projet Interreg **FabricAr3v** Interreg-project FabricAr3v (2019–2022):

→ → Projet OpenSource visant à créer des moyens de FAM à **moins de 30 k€**, se basant sur le principe d'extrusion.

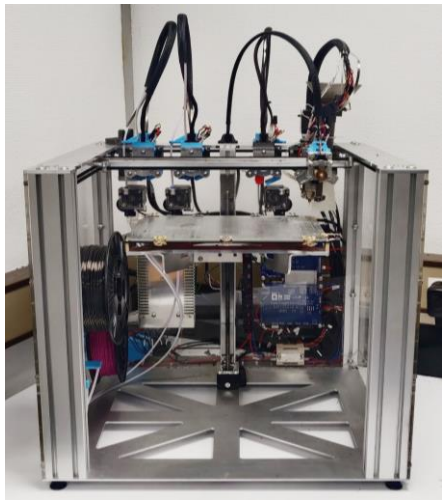
→ Open-sourceproject gericht op het ontwikkelen van metaal-additieve fabricagemiddelen **onder de 30 k€**, gebaseerd op het extrusieprincipe.

→ Maîtriser toute la chaîne De volledige keten beheersen

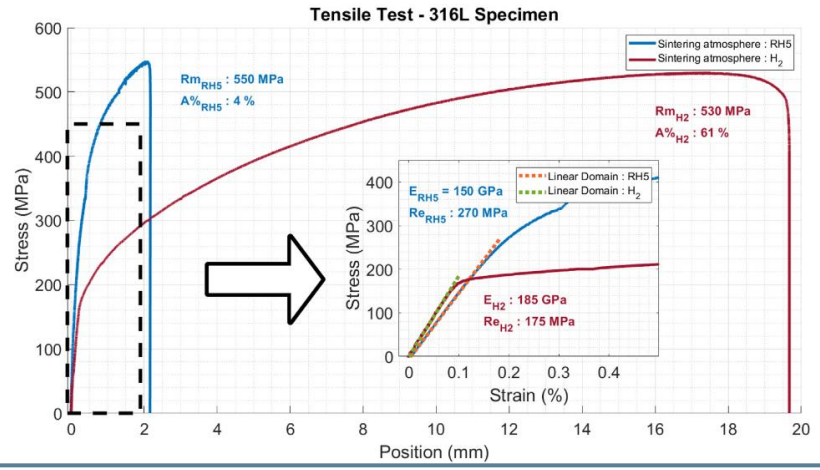
⇨ Rendre FAM accessible à tous : PME, FabLab, particuliers …
Toegankelijke metaal-AM voor kmo's, fablabs en particulieren

V. Martin PhD (2019 - 2023)

Imprimante Printer

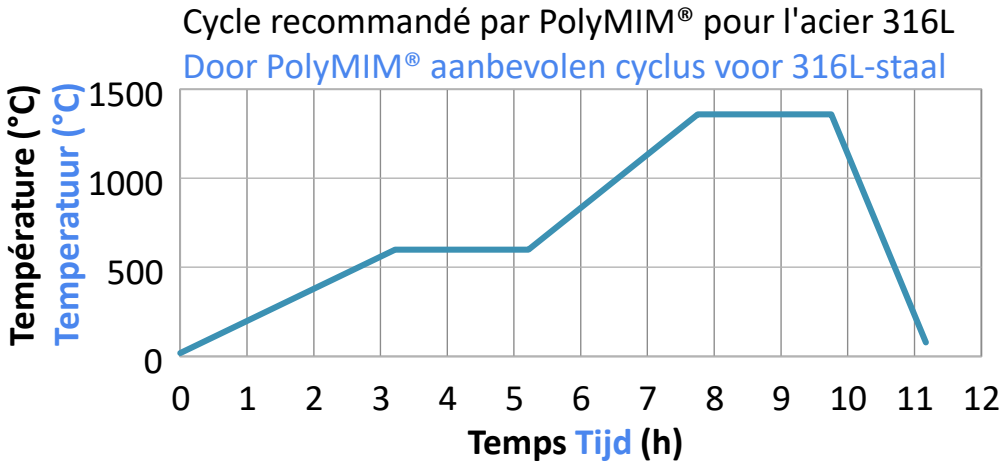


Premiers essais mécaniques (preuve de concept) :
Eerste mechanische proeven (proof of concept):



Problématique de la thèse CIFRE de S. Badin
CIFRE-theseproblematiek (S. Badin)

FAM accessible à tous : Solution économique pour le déliantage thermique et frittage ?
Toegankelijke metaal-AM: economische oplossing voor ontbinden en sinteren?



Le cycle thermique dédié au MIM pour l'acier inoxydable 316L reste-t-il adapté au MIM-like et à l'utilisation de fours économiques ?
Is de MIM-thermische cyclus voor roestvast staal 316L geschikt voor MIM-achtige processen en betaalbare ovens?

En industrie, frittage sous hydrogène (H_2)
In de industrie: sinteren onder waterstof (H_2)
→ Nécessite infrastructures de protection (€€)
→ Vereist beschermingsinfrastructuur (€€)

Est-il possible de substituer l'hydrogène par un autre gaz plus simple d'emploi ?
Is het mogelijk waterstof te vervangen door een ander gas dat eenvoudiger in gebruik is?

Matériau et Procédé

Materiaal en proces

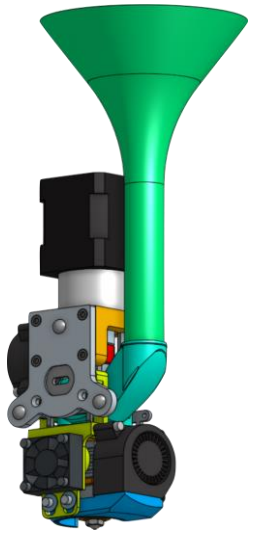
Stratégie d'impression et conditions de déliantage chimique

Feedstock → Impression Printen → Déliantage chimique Chemisch ontbinden → Déliantage thermique Thermisch ontbinden → Frittage Sinteren

Acier inoxydable 316L

Roestvast staal 316L

(PolyMIM®)



Tête d'impression 3D pour granulés (Mahor XYZ, modifiée)

3D-printkop voor pellets (Mahor XYZ, aangepast)

Pièce verte imprimée

Geprint groen onderdeel

	TPU	316L
Température d'impression (°C) Printtemperatuur (°C)	205	195
Température du plateau (°C) Bouwplaattemperatuur (°C)	60	
Vitesse d'impression (mm/s) Printsnelheid (mm/s)	30	20
Hauteur des couches (mm) Laagdikte (mm)	0.2	0.2
Largeur des cordons (mm) Lijnbreedte (mm)	0.6	0.6
Débit (%) Debiet (%)	100	100
Chevauchement de remplissage (%) Vuloverlap (%)	10	50

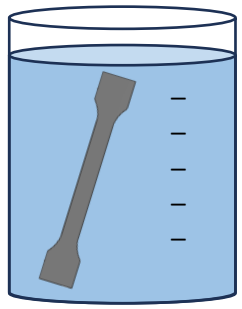
Stratégie impression Printstrategie :

+/- 45° avec 2 parois **100% remplissage**

± 45° met 2 wanden, 100% vulling

Déliantage à l'eau

Ontbinden in water



60°C pendant 48h

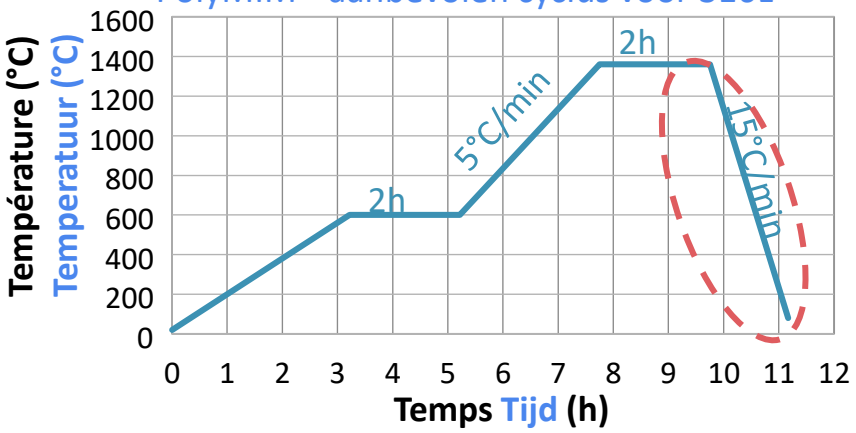
60 °C gedurende 48 u

Conditions de déliantage thermique et de frittage

Feedstock → Impression Printen → Déliantage chimique Chemisch ontbinden → Déliantage thermique Thermisch ontbinden → Frittage Sinteren

Cycle recommandé par PolyMIM® pour l'acier 316L

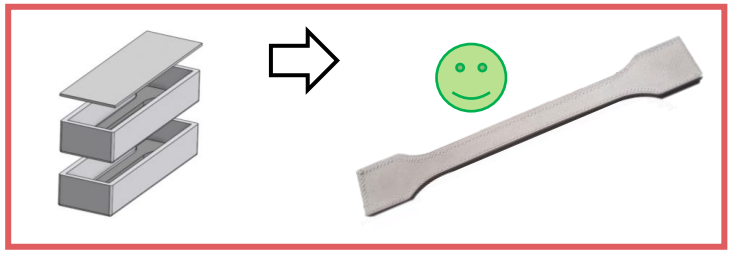
PolyMIM®-aanbevolen cyclus voor 316L



- Déliantage Ontbinden 600°C
- Frittage Sinteren 1360°C

Contrainte fours laboratoires : **5°C/min max**

Labovens: **max. 5 °C/min**



~ 400 k€

Four batch Batchoven
(Elnik)

Hydrogène Waterstof (H_2)

Four industriel (CRITT)

Industriële oven (CRITT)

~ 40 k€

Four tubulaire
Buisoven
(Pyrox)

Ar

N_2

RH5 (10% H_2 + 90% N_2)

~ 5 k€

Four tubulaire
Buisoven
(Sager)

Déliantage
Ontbinden N_2
+
Frittage Sinteren

Vide primaire

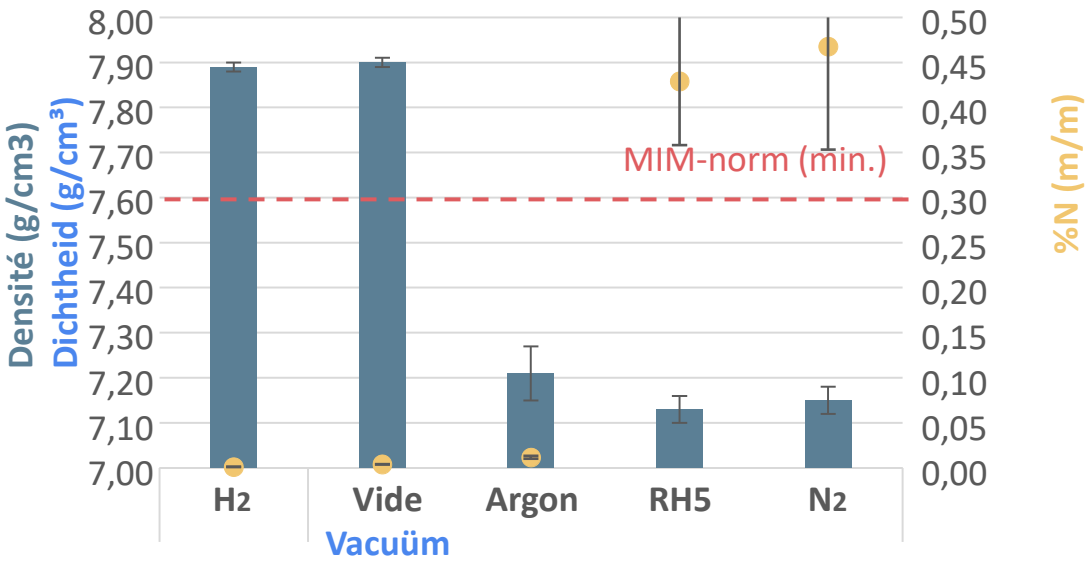
Primair vacuüm

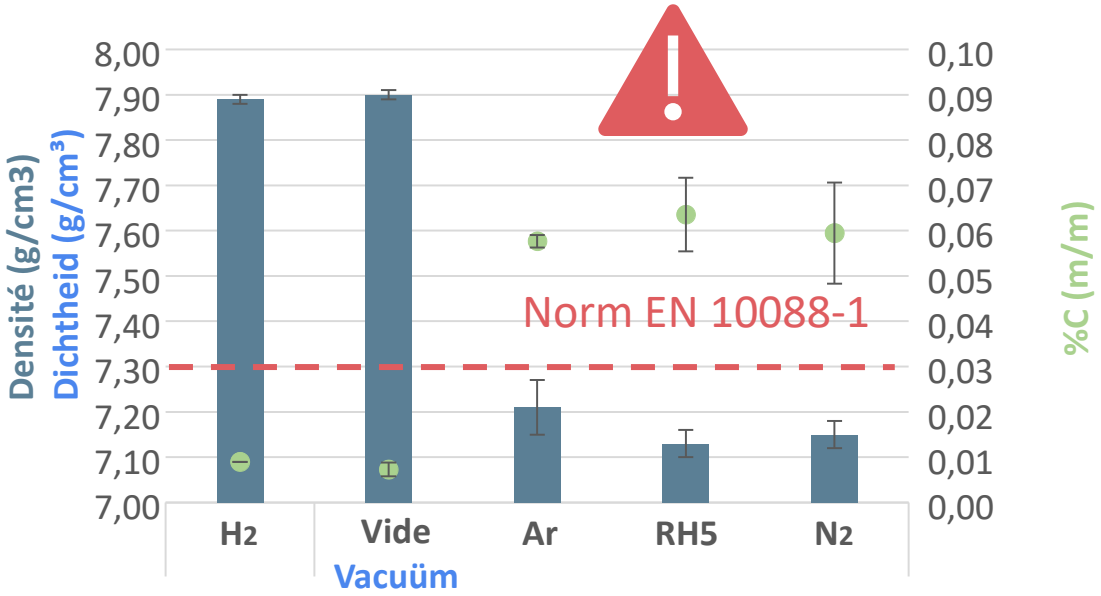
Fours de laboratoire Laboratoriumovens (LaMcube)

Influence des conditions de frittage

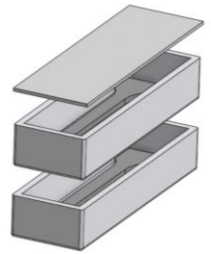
Invloed van de sintercondities

Densité et composition chimique
Dichtheid en chemische samenstelling



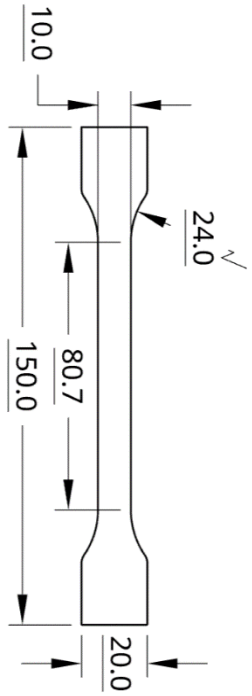


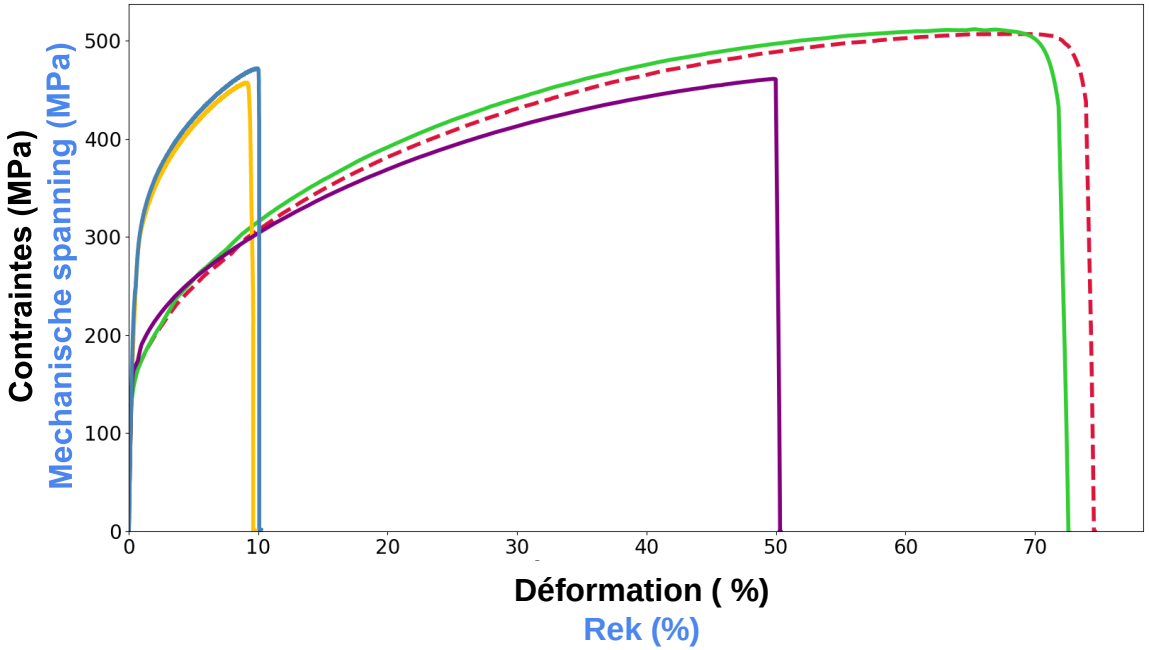
H_2 et vide > norme MIM ASTM B883-10 (min.)
H_2 en vacuüm > MIM-norm ASTM B883-10 (min.)

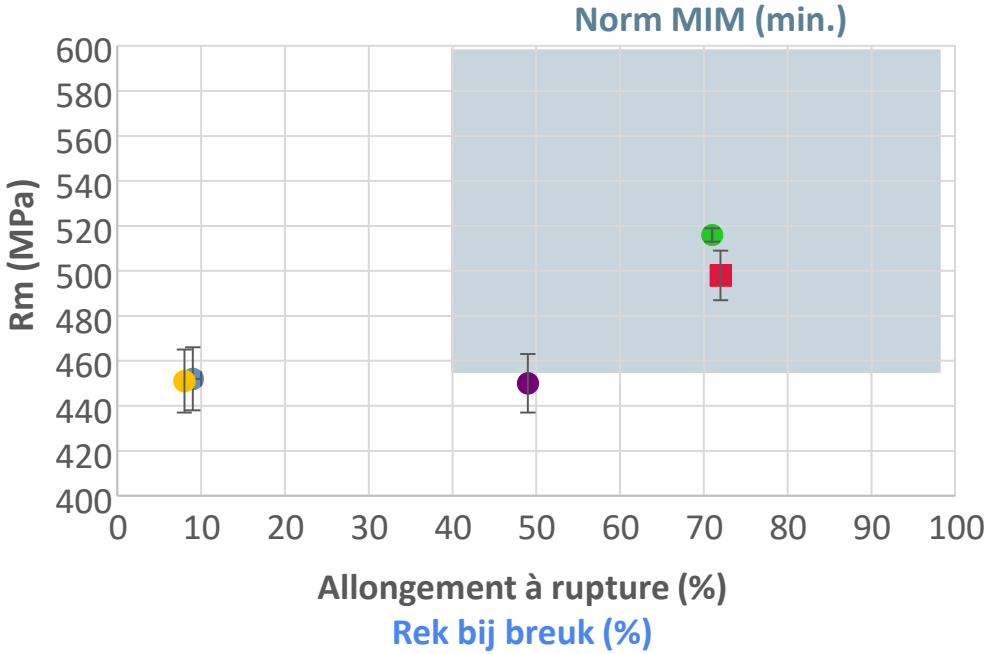


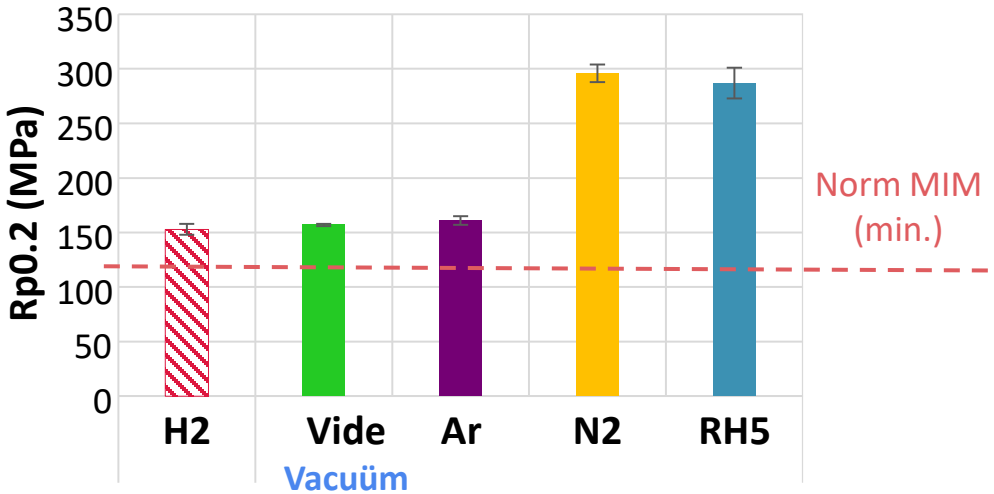
- RH5, N_2 : Dissociation du diazote en azote monoatomique
  Dissociatie van distikstof tot monoatomisch stikstof
- RH5, N_2, Ar : Carbone issu de la dégradation des polymères piégés dans les creusets
  Koolstof afkomstig van de afbraak van polymeren, vastgehouden in de kroezen

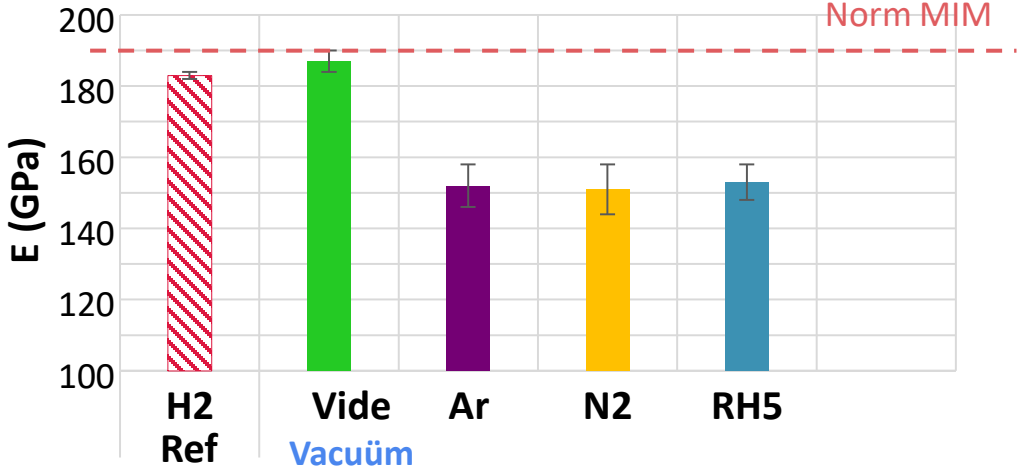
Propriétés mécaniques de traction
Mechanische trekeigenschappen



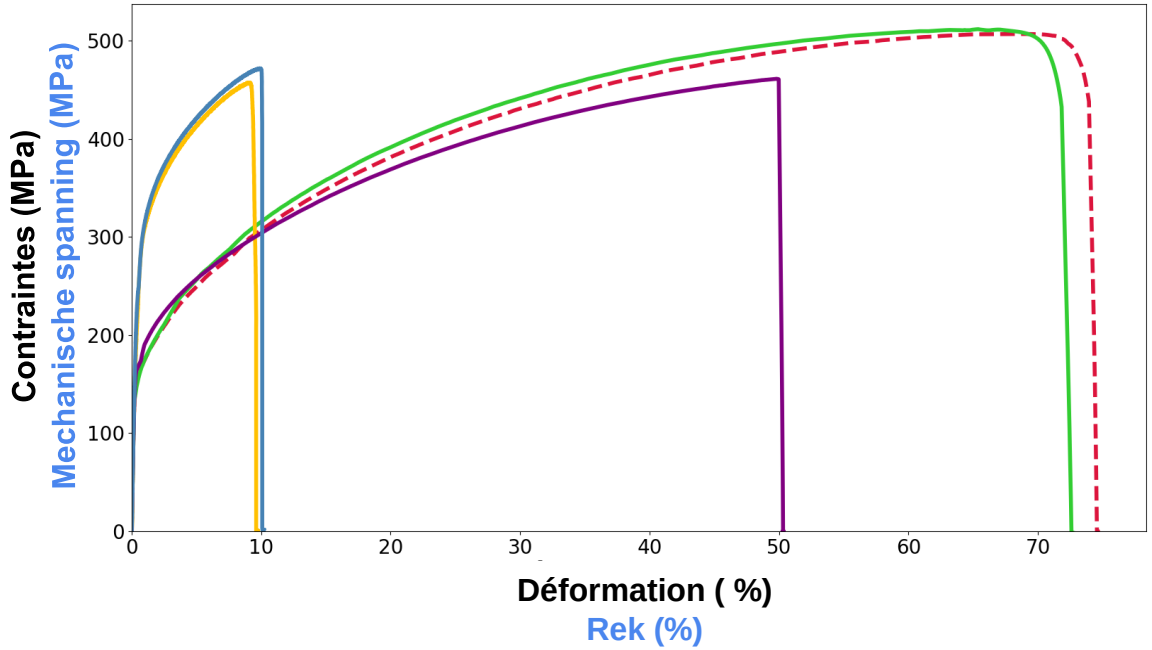






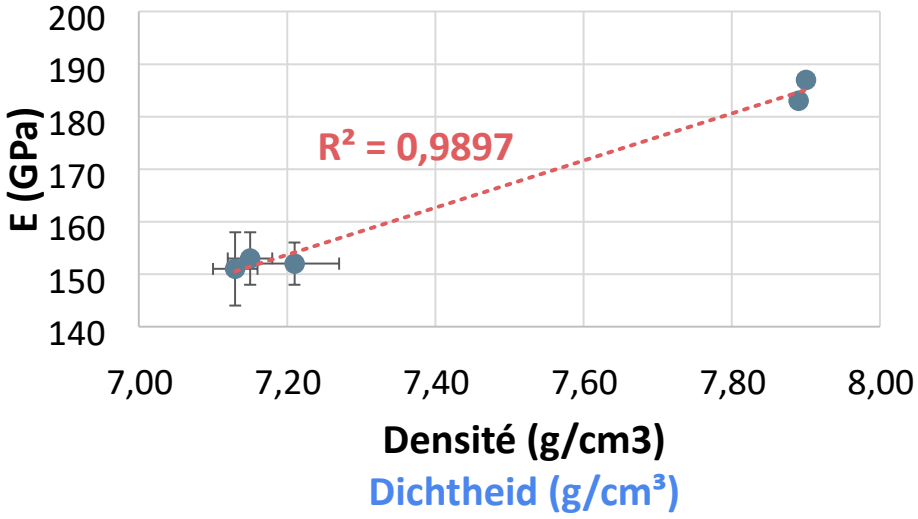


Mise en corrélation des propriétés mécaniques de traction
Correlatie van de mechanische trekeigenschappen



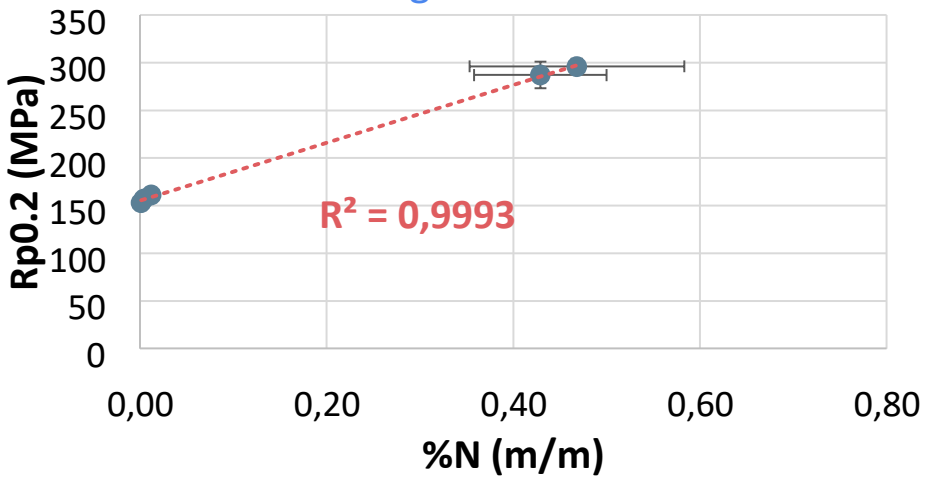
Module de Young vs densité

Elasticiteitsmodulus versus dichtheid



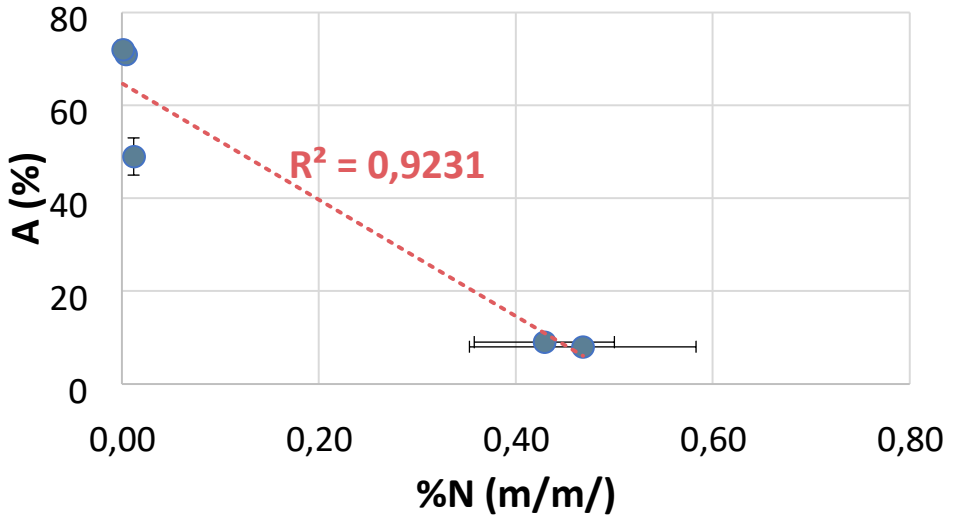
Limite élastique vs %N

Vloeigrens versus %N

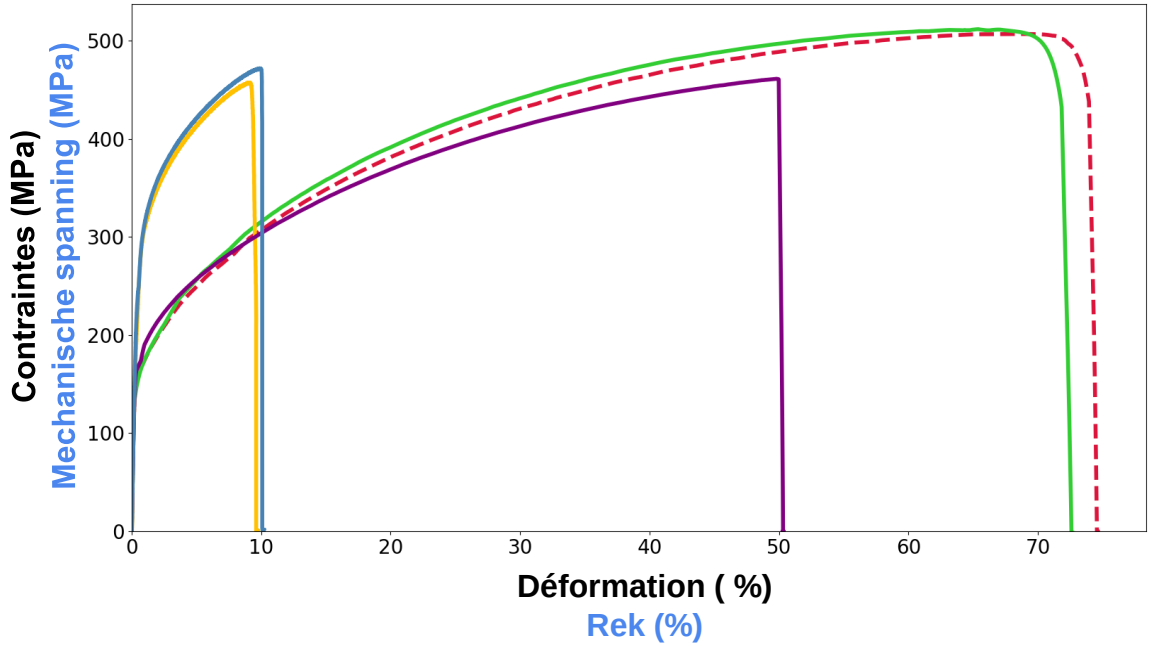


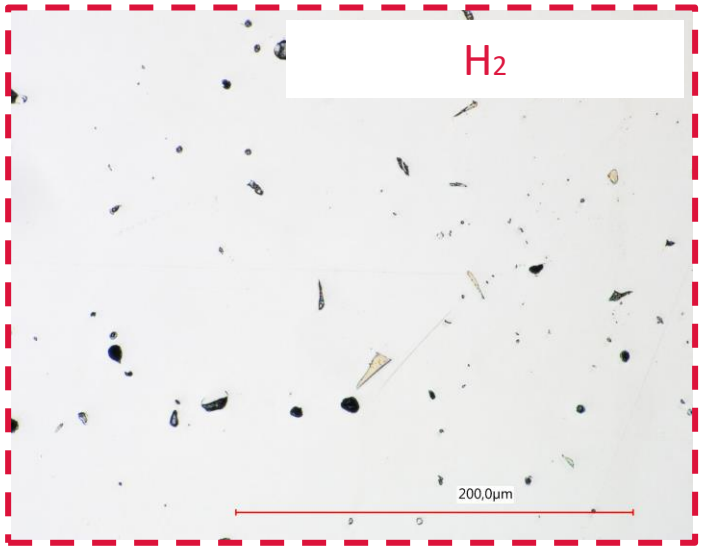
Allongement à la rupture vs %N

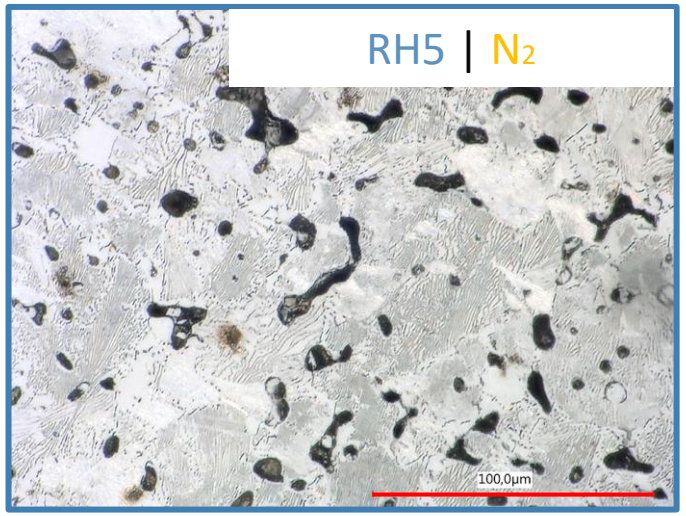
Rek bij breuk versus %N



Mise en corrélation des propriétés mécaniques de traction
Correlatie van mechanische trekeigenschappen



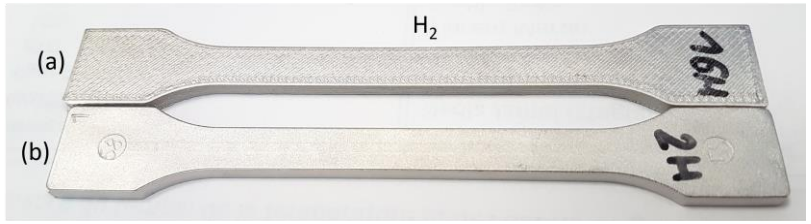




Résistance à la corrosion généralisée
Weerstand tegen algemene corrosie

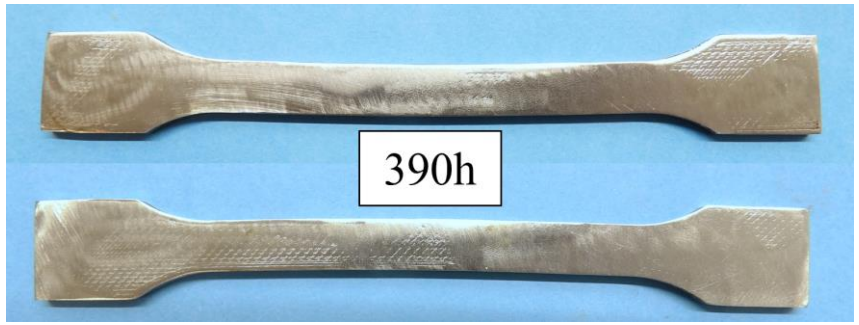
Brouillard salin NaCl 5%, 35°C (norme ISO 9227) polissage grade 600 avec analyses visuelles allant de 1h à 390h

Zoutnevel NaCl 5%, 35 °C (ISO 9227-norm), polijsten tot korrel 600, met visuele analyses van 1 u tot 390 u



H2

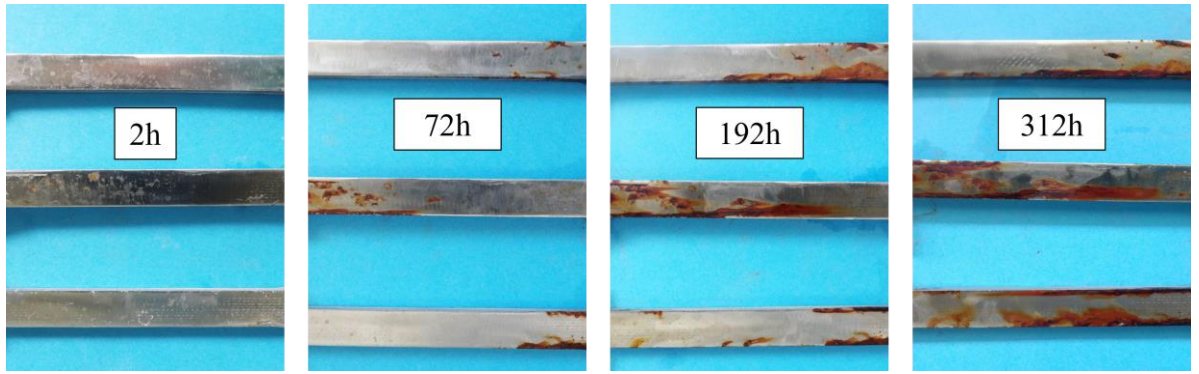
Pas de traces de rouille
Geen sporen van roest



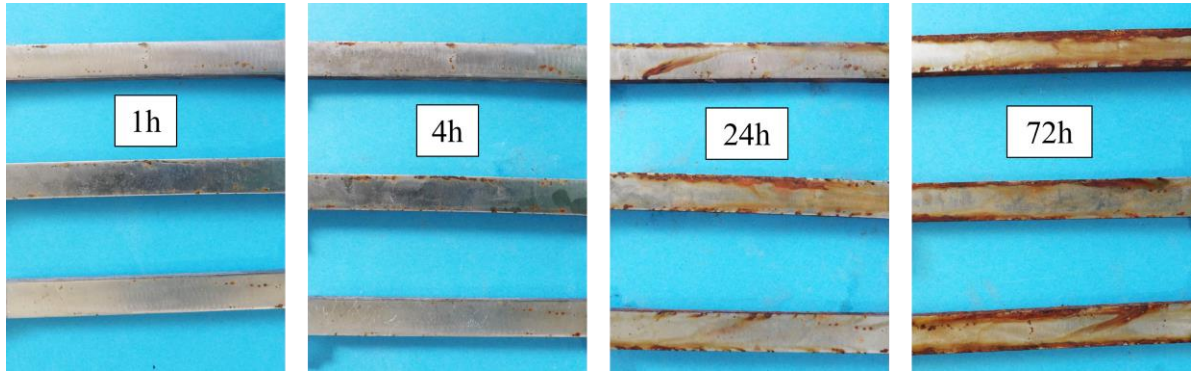
VIDE
Vaccuüm

1ère traces de rouille à 72 h, sans évolution ultérieure.
Eerste roestsporen na 72 u, zonder verdere evolutie.

Ar



RH5 et N2



Forte dégradation de la résistance à la corrosion généralisée excepté sous vide
Sterke afname van de weerstand tegen algemene corrosie, behalve onder vacuüm

Conclusions Conclusies

&

Perspectives Vooruitzichten

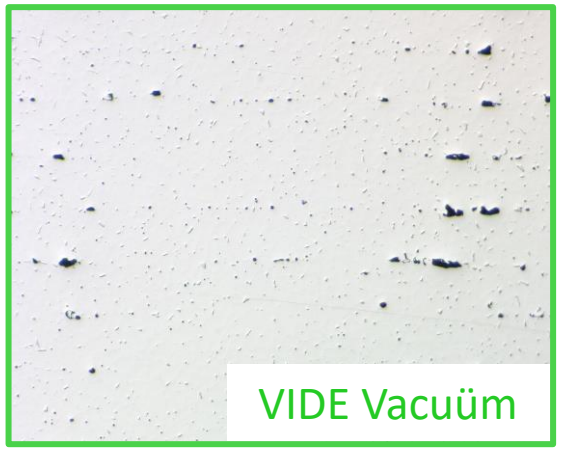
Conclusions

		Coût Kosten	Résistance à la corrosion Corrosiebestendigheid	Comparaison avec la norme MIM Vergelijking met de MIM-standaard				
				Densité Densité	Limite élastique Elastische limiet	Résistance à la rupture Breeksterkte	Allong. à la rupture Rek bij breuk	Module de Young Youngs modulus
Four industriel Industriële oven	H2	€€€	++	+++	+	++	+++	++
Four de lab. + pièces confinées Laboratoriumoven + besloten ruimtes	Ø	€	+	+++	+	++	+++	++
	Ar	€€	-	-	++	-	++	-
	N2 RH5	€,€€	- -	--	+++	-	- - -	-

- Une nouvelle génération de FAM qui peut allier performance mécanique, coût réduit et durabilité
  Een nieuwe generatie metaal-AM die mechanische prestaties, lagere kosten en duurzaamheid combineert
- Frittage sous vide = MIM-like conformes aux normes applicables aux pièces injectées par MIM
  Sinteren onder vacuüm = MIM-achtige onderdelen conform de normen die gelden voor via MIM geïnjecteerde onderdelen
  - → Stratégie développée dans le cadre du projet FabricAr3v → Ok
    Strategie ontwikkeld in het kader van het FabricAr3v-project → OK
  - → Démontre la possibilité d'utiliser des équipements plus économiques
    Toont de mogelijkheid aan om meer economische apparatuur te gebruiken

Perspectives Perspectieven (1/2)

- **Amélioration de la résistance à la corrosion = enjeu crucial pour le 316L**
  Het verbeteren van de corrosiebestendigheid is een cruciaal punt voor 316L



Élimination des porosités
Eliminatie van porositeit

- Hybridation (impression + usinage) → Sur-extrusion → Diminution des porosités
- Augmentation temps/température frittage
- Hybridisatie (printen + bewerken) → Over-extrusie → Verminderde porositeit
- Verhoogde sintertijd/temperatuur

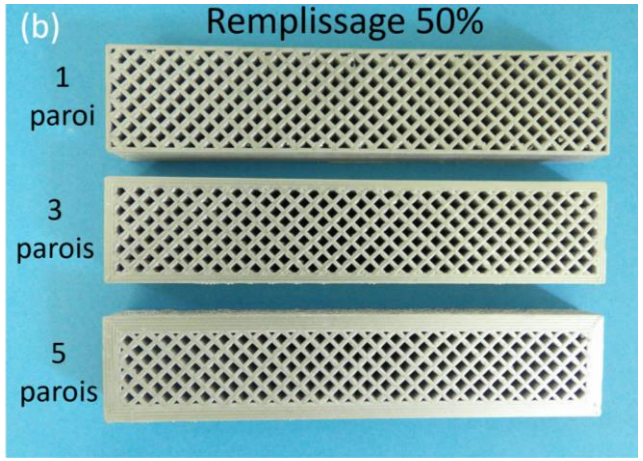
Temps/T° palier austénitisation
Tijd/temperatuur austenitisatieplateau

- Elimination de la ferrite et des phases fragiles
- Adaptation des paramètres à la dimension des pièces
- Verwijdering van ferriet en brosse fasen
- Aanpassing van parameters aan de afmetingen van de onderdelen

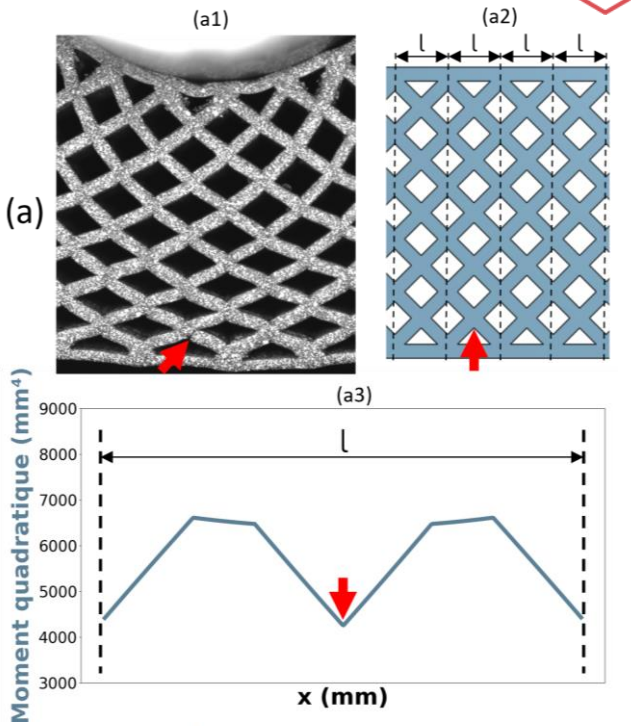
Optimisation et validation
Optimalisatie en validatie

- Brouillard salin après hypertrempe
- Tests corrosion approfondis
- Hypertrempe sur pièces complexes
- Zoutneveltest na ultrasnel afkoelen
- Uitgebreide corrosietests
- Ultrasnel afkoelen van complexe onderdelen

Perspectives Perspectieven (2/2)



- Étudier d'autres paramètres structuraux
  Bestudeer andere structurele parameters
- Développer des nouveaux modèles pour la simulation numérique des structures en treillis
  Het ontwikkelen van nieuwe modellen voor de numerieke simulatie van roosterstructuren
- Multiplier les caractérisations et la nature des essais mécaniques
  Verhoog het aantal karakteriseringen en de soorten mechanische tests.
- Imprimer des pièces complexes
  Print complexe onderdelen
- Maîtriser les tolérances dimensionnelles : retrait, déformations, rugosité
  Beheersing van maattoleranties: krimp, vervorming, ruwheid
- Appliquer la démarche sur d'autres matériaux
  Pas de aanpak toe op andere materialen.



Interreg
Cofinancé par l'Union Européenne
Medegefinancierd door de Europese Unie
France - Wallonie - Vlaanderen
CrossS3
TECH4FAB-Cross S3

Interreg
Cofinancé par l'Union Européenne
Medegefinancierd door de Europese Unie
France - Wallonie - Vlaanderen
Inside 3D

LaM CUBE
Laboratoire de mécanique, multiphysique, multiéchelle

CRITT
MATÉRIAUX INNOVATION

Merci pour votre attention !

Université de Lille

cnrs

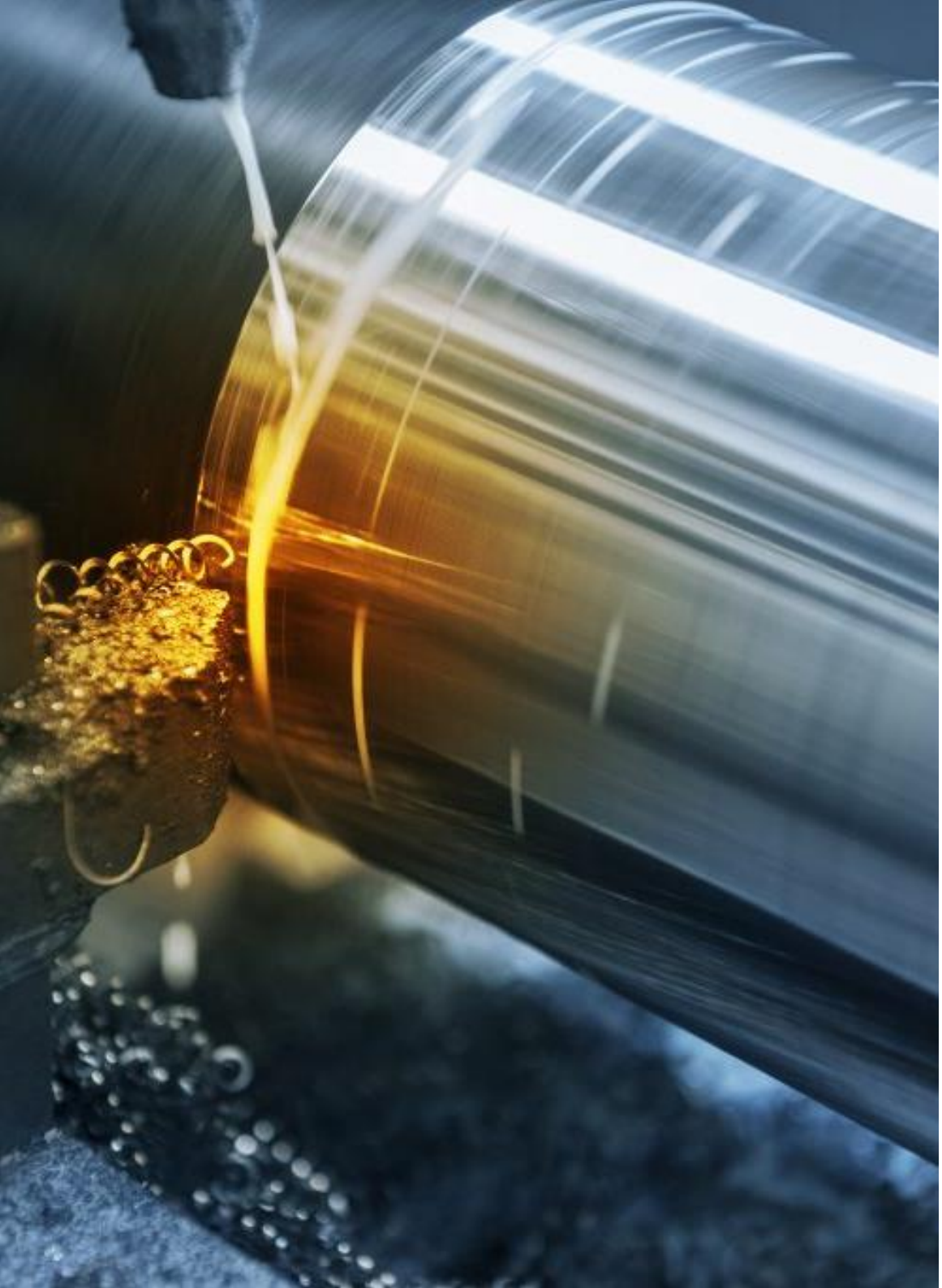
centralelille

Pam AM Systems

Pellet Additive Manufacturing Solution

pollen

your chemistry inside



#01
General overview

- Key figures
- Value proposition
- Markets & applications

Key Figures

12 years of innovation in Additive Manufacturing

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2016

commercial launch of the first generation of Pam 3D printers, after 5 years of R&D.

AIRBUS SANOFI DECATHLON Electrolux

12+ years

of R&D & continuous improvements.

100%

independent for autonomous decision making.

70%

industrial customers, from consumer goods, healthcare to aerospace applications.

90+

qualified materials thermoplastics, metal alloys & technical ceramics.

25+

countries, mainly in Europe and Asia.

6th generation

of products integrating the latest innovations and a new range of accessories and options to meet performance applications.

30+

different configurations, Pam systems modular architecture to offer the optimal setup for demanding materials.

130+

systems deployed and more than 30 % are operated outside Europe.

4

products to cover the largest range of materials : thermoplastics, Metals & Ceramics and applications.

400+

3D printing parameters, to get total freedom and determine the best compromise between productivity and quality.

7

distributors to cover international markets.

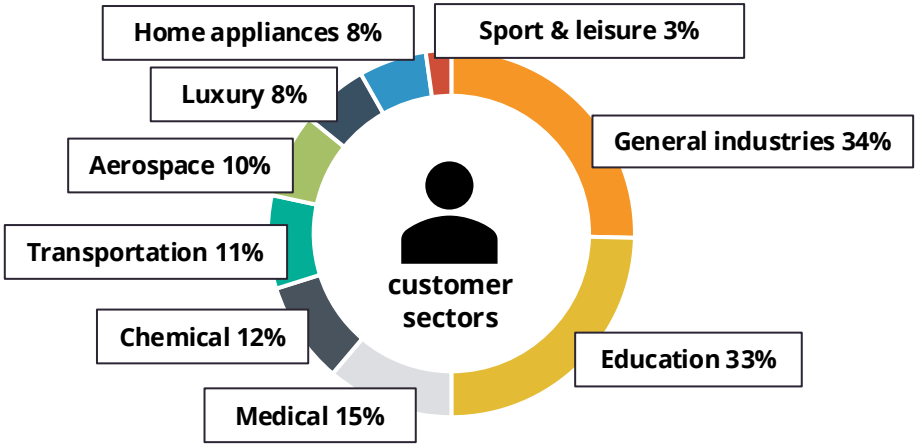
Value Proposition

Make profit with small and medium series - Your chemistry inside

Markets & Applications

Cover almost all market needs

Addressed markets



Industrial	Pam is used for **right material prototyping and small series production**.
Education	Mainly used for R&D applications on **new material development and processes**.
Medical	Use for prospective applications such as **new pills, orthopaedic prosthesis and new materials**.
Chemical companies	Used on material demonstration to **develop new applications for their clients** and push Pam usage with their chemistry.
All other sectors	Used for right material prototyping, design, tooling, production and spare parts. **Time-to-market reduction is a key success factor**.

Key customers & applications

Key customers

Industry

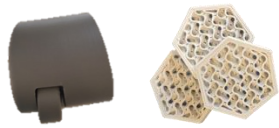
AIRBUS, Alliance-mim, BASF The Chemical Company, BIC, Chanel, Electrolux, essilor, KRAIBURG, Louis Vuitton, Michelin, ptt Global Chemical, SANOFI, SNCF, Valeo, WÜRTH

Education

cea, cnrs, CRIBC member of EMRA, DLR, INSA

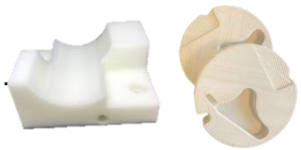
Applications

Prototyping

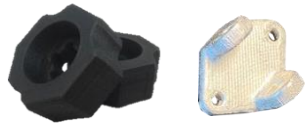


Spare parts

Tooling



Production



Pollen AM has a strong multi-market expertise allowing to address the challenges of the industrial and education markets.

#03
pam AM Solution

- pam Systems Range
- Unique AM Solution
- pam Software Ecosystem

Pam Systems Range

From commodity material to metal alloys & technical ceramics

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Key differentiating elements

- ✓ **Unique** pellet additive manufacturing solution
- ✓ Full setup control for **agile manufacturing**
- ✓ **Same Material as Injection Moulding** *(thermoplastics, TPEs & PIM feedstocks)*
- ✓ A **no health hazards solution** *(no volatile powders)*
- ✓ **Largest elastomers compatibility** *(from Shore 00 to Shore D)*
- ✓ Multi-material applications **with up to 4 materials**
- ✓ Properties **combination** *(hard and soft materials)*
- ✓ **Most profitable** PiM-Like additive manufacturing solution

	pam o2	pam o2 HT	pam o2 MC	Pam Pro
				NEW 
Number of extruders	From 2 to 4	2	From 2 to 4	up to 2
Maximum extrusion temperature	350°C	450°C	450°C	300°C
Extruder	Standard	HT	Reinforced	High Shear
Applications	R&D, Prototyping, Tooling, Small Series	R&D, Prototyping, Tooling, Small Series	R&D, Prototyping, Tooling, Small Series	R&D, Prototyping, Tooling, Production
Calibration	Semi-automated	Semi-automated	Semi-automated	Fully automated
AI camera	✗	✗	✗	✓
Tooch screen	✗	✗	✗	✓
Commodity materials	✓	✓	✓	✓
TPEs materials	✓	✓	✓	✓
Performance materials	✗	✓	✓	✗
Metal alloys – [MIM feedstock]	✗	✗	✓	✗
Technical ceramics – [CIM feedstock]	✗	✗	✓	✗

Unique Additive Manufacturing Solution

Strengths of PAM technology based on different point of view

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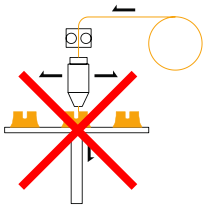
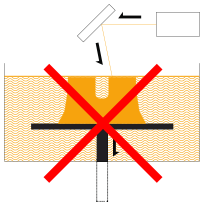
Using universal materials

- ✓ No filaments
- ✓ No powders
- ✓ No resins

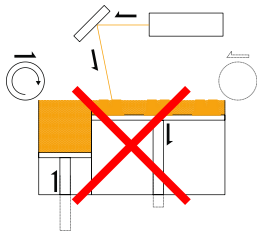
It is <u>not</u> FFF



It is <u>not</u> SLS



It is <u>not</u> SLA



We only use industrial grade materials in the shape of pellets.

Why?

Because we trust that the industry needs the **right chemistry** at its **right cost & compatible with traditional manufacturing** processes is key.

The most innovative and complete material portfolio

ALBIS · ARKEMA · BASF The Chemical Company · Celanese · covestro

DOW · EASTMAN · INEOS STYROLUTION · INMATEC Technologies GmbH · KRAIBURG

LATI · LEHVOSS Group · LOTTE CHEMICAL · mcpp Power to Perform · NatureWorks

POLYMIM · SOLVAY · TOTAL · Bring your own material ...

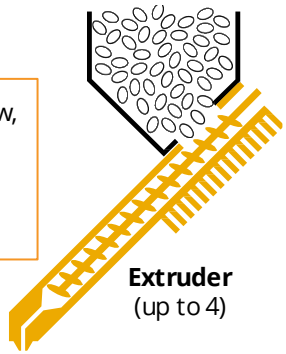
PAM extrusion process

Contains 1L of pellets

Material cartridge

The material cartridge is reusable and can be refilled on the fly. A feeder is integrated to **ensure good material flow.**

The extruder is composed of a **cylinder**, an Auger screw, **heating elements**, **fans** and **thermocouples**
Rotation of the Auger screw is controlled by the system:
- the material flow **is linked to the screw speed**
- retract function is assured by inverted screw rotation



Extruder (up to 4)

Material deposition

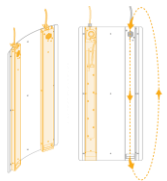
Throughout extrusion nozzles, controlled flow of fused material is **deposited layer** by **layer** on the build plate.

Modular 3D printers, focus on some accessories & options

Nozzles
9 sizes and different alloys are available to fit application needs.

Heating radiant disc
to create a thermal boundary on the part being produce.

Heating build plate
Interchangeable to suit material specifications. A 200°C version is available.



Heating room chamber
control the temperature of the building room <90°C to enhance parts properties

Pam Software Ecosystem

A global solution to meet all the stages of a project

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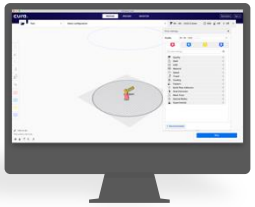
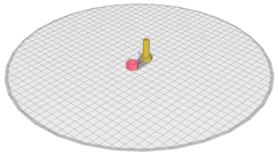
Most popular slicing solution

Cura powered by Pollen AM is the slicing software used to **prepare the 3D files** to be produced with Pam 3D printers.

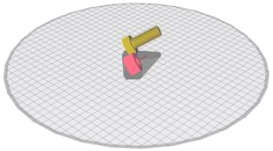
3D file → Slicing software → G.Code file



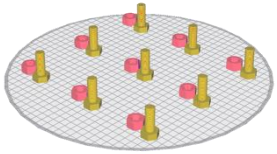
- ✓ **Flexible**, use standard 3D printing profile, adapt it or create new ones
- ✓ Expert mode gives access to up to 400 different settings for a **granular control**
- ✓ **Large range of compatible files** (STL, OBJ, X3D, 3MF, BMP, GIF, JPG, PNG)



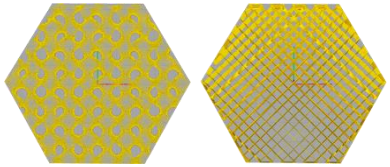
Import 3D files, select material & parameters



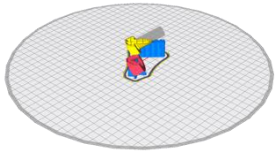
Scale, move, change orientation



Prepare production batch



Choose the infill density (from hollow to 100%) & the infill pattern (up to 13)



Slice, visualize & export file

Custom software for demanding industrials

HoneyPrint is the Pam 3D printers **control software, used to manage the production**, it is accessible by any connecting device.

G.Code file → HoneyPrint software → 3D printed part

- ✓ Specifically **engineered for Pam 3D printers**
- ✓ Allow **real-time & precise control** on the system
- ✓ A "**laboratory mode**" is accessible to allow the realization of R&D activities
- ✓ Access and retrieve **production data**

E-learning & interactive knowledge platform

PollenHive is an interactive tool for **self-service knowledge and project support solution**.

PollenHive

- ✓ Connect to the **installation & setup program**
- ✓ **Progress at the appropriate speed** with the knowledge data-base & maintenance program
- ✓ Stay up to date with all the **materials & product news**
- ✓ Download the **software updates**
- ✓ Access to the **3D printing profiles marketplace**

#04
Demonstrations

- Standard materials
- Performance materials
- TPE materials
- Metal alloys
- Technical ceramics
- Use cases

Standard thermoplastics

From prototyping to commodity applications

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your chemistry inside

Large valve actuator - PLA

This part is 25 cm large (9,8 inches) and is made of PLA. It was 3D printed as a prototype demonstrator to **ensure the product had the right fit**. And thanks to a 1,2 mm nozzle, the print went fast, lasting only 5 hours.

Nozzle size: Ø 1.2 mm

Layer height: 0.6 mm

Part weight: 606,80 g

Part size: Ø 250 x H 145 mm

Material cost: € 3.33

Material supplier: NatureWorks

Coupling Sleeve - ABS

This coupling sleeve is a part that is declined in a large number of references and is produced in small unit quantities.

The production of this part in 3D printing allows to avoid the tooling production, to produce locally and on demand while avoiding the storage with the **right properties at right prodcution** cost.

Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 62,22 g

Part size: Ø 60 x H 42 mm

Material cost: € 0.34

Material supplier: INEOS STYROLUTION

Sealable and watertight bottle - PP

This bottle has been 3D printed in PP. It represents a clear example of Pam's capacity to 3D print parts **with sealed function and functional threads**.

Ideal for food contact applications, PP also exhibits chemical resistance. Being the most widely used polymer.

Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 16.85 g

Part size: Ø 50 x H 80 mm

Material cost: € 0.08

Material supplier: TOTAL

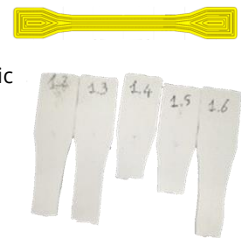
Mechanical test results

Material information :
- Grade : ABS
- Supplier : Lotte
- Reference : Starex

3D printing parameters :
- Nozzle size : 0.4 mm
- Layer height : 0.2 mm
- Infill density : 100%
- Infill pattern : concentric

Properties	Injection Moulding	Pam	Pam performance
Flexural Modulus (ASTM D790) [Mpa]	2200	2540	111 %
Young's Modulus (ASTM D6381) [Mpa]	2450	2620	107 %
Stress at Yield (ASTM D6381) [Mpa]	44.9	48.9	109 %
Strain at Yield (ASTM D6381) [%]	2.5	2.8	112 %
Strain at Break (ASTM D6381) [%]	30	30	100 %

Concentric (CC)



Specimens 3D printed with Pam in the X/Y plane show better mechanical performances than IM.

Performance thermoplastics

Meet the demanding requirements of the market

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Turbine - PESU

This turbine is made of PESU. Taking into consideration its concave and **convex elements**, the part was 3D printed to avoid supporting material, hence **reducing production time and ensuring maximal strength** for the material.

PESU is a **high-performance material** with a temperature profile that is unique among engineering thermoplastics, it can be a substitute for metal, and technical ceramics.

Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 22.36 g

Part size: Ø 60 x H30 mm

Material cost: € 1.12

Material supplier: BASF The Chemical Company

Gear - PC

This straightforward gear made of PC, a performance material used in **applications requiring good shock and temperature resistance**.
This **LED grade can achieve good light transmission**.

This material is very resistant to impacts, has excellent mechanical properties that are characterized by low expansion and low heat distortion.

Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 6,26 g

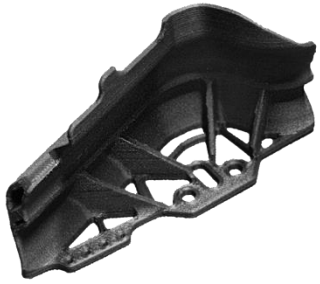
Part size: Ø 46 x H22 mm

Material cost: € 0.09

Material supplier: covestro

Bumper – PA 66 15CF

This bumper was printed in PA filled with 15% carbon fiber.
This part demonstrates the ability of Pam printers to **process both performance and filled materials**.
The part has **very good inter-layer adhesion, good surface finish and good dimensional accuracy**.



Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 16.85 g

Part size: L120 x W50 x H35 mm

Material cost: € 0.08

Material supplier: Lehmann&Voss&Co.

Mechanical test results

Material information :
- Grade : PA 66 – 15% carbon fiber
- Supplier : Lehvoss
- Reference : LUVOCOM® 3F PAHT® CF 9742 BK

3D printing parameters :
- Nozzle size : 0.8 mm
- Layer height : 0.3 mm
- Infill density : 100%
- Infill pattern : 2

Lines (LI)

Lines (LI90)

Series	Tensile strength Injection moulding [Mpa]	Tensile strength Pam [Mpa]	Pam performance vs Injection moulding	Tensile strength FFF [Mpa]	Pam performance vs FFF
LI	183	151	82 %	146	103 %
LI90	90	97	107 %	82	118 %

Specimens 3D printed with a Pam system show better mechanical performances than those in FFF.

TPE materials

Producing flexible AM parts without hardness shore limits becomes possible

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Car light sealing – TPU 33 Shore D

This vintage car headlight bracket was no longer available and needed to be replaced.

After being redesigned, the part was produced in TPU with a hardness of 33 Shore D TPU **allowing a good holding of the headlight while ensuring the waterproof function**.

Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 77.03 g

Part size: L175 x W80 x H80 mm

Material cost: € 1.08

Material supplier: BASF The Chemical Company

Snorkel Mouthpiece – TPE 70 Shore A

This snorkel mouthpiece is 3D printed **in TPE 70 Shore A**.

With excellent mechanical properties, good inter-layer adhesion, and a very good surface finish, this material is a **good alternative to silicones**.

Recyclable and skin contact, this material meets a large number of **industrial needs**.

Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 9.20 g

Part size: L60 x W16 H64 mm

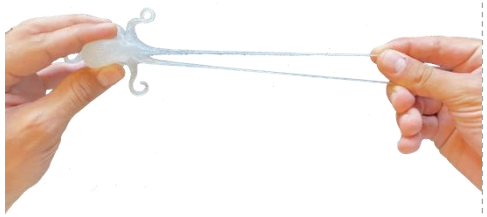
Material cost: € 0.13

Material supplier: KRAIBURG

Octopus toy – 30 Shore 00

This octopus toy is 3D printed with an **extremely flexible TPE** (30 Shore 00).This toy is a demonstration of the ability of Pam printers to transform flexible materials without hardness limits. This is **not possible with conventional 3D printers**.

This material is skin contact and meets the toy standard.



Nozzle size: Ø 0.8 mm

Layer height: 0.4 mm

Part weight: 10.35 g

Part size: L80 x W80 x H32 mm

Material cost: € 0.14

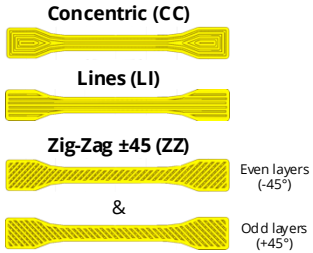
Material supplier: KRAIBURG

Mechanical test results

Material information :
- Grade : TPE
- Supplier : Kraiburg TPE
- Reference : TC6MLB

3D printing parameters :
- Nozzle size : 0.8 mm
- Layer height : 0.3 mm
- Infill density : 100%
- Infill pattern : 3

Properties	Injection Moulding	Pam (CC)	Pam (LI)	Pam (ZZ)
Tensile Strength (DIN 53504/ISO 37) [Mpa]	4.5	4.49	4.5	4.6
Elongation at Break (DIN 53504/ISO 37) [%]	550	497	540	584
Tensile Strength comparison		99 %	100 %	102 %
Elongation at Break comparison		90 %	98 %	106 %



A good 3D printing strategy allows to obtain mechanical properties equivalent or superior to IM.

Multi-material parts

Combining up to 4 different materials and properties is possible

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Bellow using support material – TPU 33 Shore A

Destined to the automotive market, this bellows has been manufactured using a **TPU 33 Shore D for the structure material** & **PVOH** (water-soluble material) **to support cantilever part elements**.

The removal of this support material is achieved by plunging the part into a tempered water tank. Once the support material is removed, the bellows is fully functional with the required flexibility.

Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 15.00 g

Part size: Ø 55 x H 75 mm

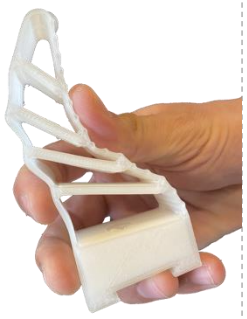
Material cost: € 0.43

Material suppliers: BASF The Chemical Company, kuraray

Robot multi-material gripper – ABS & TPE 70 Shore A

With the increase of robots in manufacture and assembly lines, the production of grippers is on the rise. Pam 3D printers multi-material capability make it possible to **associate flexibility with rigid materials**.

In this example ABS and TPU 33 Shore D create a perfect combination for gripping effect.



Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 29.56 g

Part size: L 110 x W 45 x H22 mm

Material cost: € 0.59

Material suppliers: KRAIBURG, INEOS STYROLUTION

Multimaterial shoe outsole

This prototype required 2 TPEs (45 Shore A & 70 Shore A); a structural material was needed to allow the production of the cantilevered elements. A total of **3 materials were needed**.

It has good mechanical properties and good surface finish. The production of right material prototypes allows to **reduce iterations time** (±90 days), to **avoid the tooling production** (± 18 000 € / prototype), etc.

ADD LAB, DECATHLON

Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 16.85 g

Part size: L 275 x W 85 x H 45 mm

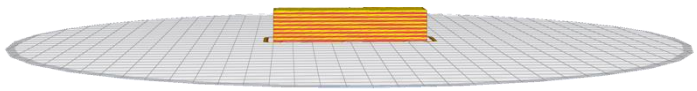
Material cost: € 0.08

Material suppliers: KRAIBURG, INEOS STYROLUTION

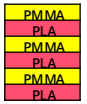
Mechanical test results

"Multimaterial PMMA/PLA parts produced with a Pam 3D printer were **successfully developed**. [...] PMMA/PLA axisymmetric multilayers **exhibit interfacial properties situated between those of the PLA and PMMA monolayers**. [...] Finally, the proposed workflow in the study can be used for manufacturing other 3D-printed multimaterials with different composition ratios and **different functional gradient properties** in view of numerous industrial applications."

Part presentation



Multilayers structure



Properties	3D printed PLA	3D printed PMMA	Injection molding PLA	Injection molding PMMA	Injection molding PLA/PMMA	3D printed PLA/PMMA @Tr=55°C
Flexural Strength [Mpa]	11.4	8.1	11.6	14.6	13.3	9.0

Extract from "3D printing of PLA and PMMA multilayered model polymers: an innovative approach for a better-controlled pellet multi-extrusion process." By Mohamed Yousfi, Ahmed Belhadj, Khalid Lamnawar and Abderrahim Maazouz

Metal alloys

3D print the widest range of metal alloys at unbeatable cost

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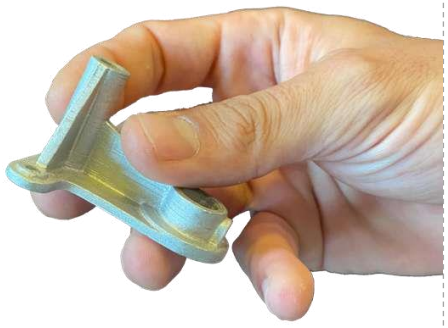
Bracket – Stainless Steel 316L

This part is presented at the sintered stage, when the part is fully metallic, with **lowest porosity**.

When produce in small and medium series, brackets are **good candidates for 3D printing**, their geometry are adapted to the shaping process.



Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 109.12 g

Part size: L 65 x W 57 x H 36 mm

Material cost: € 8.73

Material supplier: BASF The Chemical Company

Bracket – Stainless Steel 17-4 PH

This gear is presented in the sintered state, it has a **porosity ratio of < 1%** and **mechanical properties very close to those of injection molded parts**.

The 3D printed parts with conventional MIM feedstock can be **integrated in conventional debinding and sintering cycles**. No need to change industrial processes.

Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 35.59 g

Part size: Ø 58 x H 5 mm

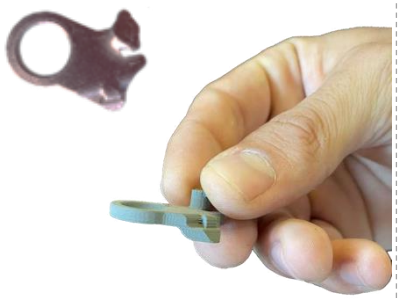
Material cost: € 2.85

Material supplier: POLYMIM

Ring Holder – Titanium Ti6Al4V

Producing titanium parts thanks to 3D printing allows to **create prototypes, but also parts in small and medium series**.

This allows, among other things, to use the **same raw material in 3D printing and injection molding**, thus simplifying the entire value chain and **avoiding material re-qualification** when it is necessary to switch from a forming technology to another one.



Nozzle size: Ø 0.25 mm

Layer height: 0.125 mm

Part weight: 4.30 g

Part size: L 30 x W 15 x H 4 mm

Material cost: € 0.65

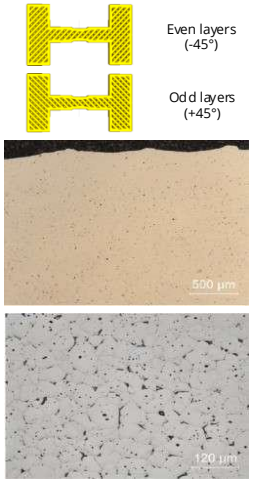
Material supplier: ELEMENT 22

Mechanical test results

Material information :
- Grade : Stainless Steel 316L
- Supplier : PolyMIM
- Reference : polyMIM® 316L D 170E

3D printing parameters :
- Nozzle size : 0.4 mm
- Layer height : 0.2 mm
- Infill density : 100%
- Infill pattern : Zig-Zag ±45°

Properties	Binder Jetting	FFF	Pam
Density [g/cm^3]	7.82	7.55	**7.90**
Porosity ratio [%]	> 1	> 1	**< 1**
Tensile Strength (EN ISO 6892-1) - [Mpa]	558	416.76	**565.84**
Elongation at Break (EN ISO 6892-1) - [%]	19.8	13.74	**21.16**



Sintered parts 3D printed by a Pam system have better performance than those obtained by the BF and FFF processes (lower porosity & higher tensile strength).

Technical ceramics

From oxides to non-oxides, make the most technical applications accessible

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Laboratory cup – Aluminium Oxide

Producing ceramic parts from **industrial CIM feedstock** that meet specifications and projects reduces costs but also **right mechanical properties**.

This part presented in a green and dense state has mechanical properties similar to the injected parts.

Nozzle size: Ø 0.4 mm

Layer height: 0.15 mm

Part weight: 28.00 g *(as sintered)*

Part size: Ø 39 x H 7 mm

Material cost: € 0.87

Material supplier: INMATEC Technologies GmbH

Architectural cylinder - Zirconium oxide

Architectural cylinder was printed in black Zirconium oxide by the Belgian Ceramic Research Centre (BCRC). Presented in a dense, pourable state, this piece shows a very good level of resolution, a good surface finish

"**When ceramic micro-extrusion reaches the resolutions of stereolithography**" – *BCRC, Dr. Fabrice Petit, Program Manager Manufacturing Processes.*

Nozzle size: Ø 0.4 mm

Layer height: 0.2 mm

Part weight: 31.22 g *(as sintered)*

Part size: Ø 28 x H 35 mm

Material cost: € 4.06

Material supplier: INMATEC Technologies GmbH

Watch case - Silicon Nitride

3D printing **non-oxide ceramics is possible** with Pam, this watch case is shown in a dense green state.

This ceramic is particularly important because the combination of its properties is unique. Extremely hard, it is highly resistant to thermal shock, chemicals and wear even at high temperatures.

Nozzle size: Ø 0.6 mm

Layer height: 0.3 mm

Part weight: 5.6 g *(as sintered)*

Part size: L 38 x W 30 x H 4 mm

Material cost: € 0.85

Material supplier: Sicerom

Mechanical test results

Material information :
- Grade : Alunimum oxyde
- Supplier : Inmatec GmbH
- Reference : Inmafeed K1008

3D printing parameters :
- Nozzle size : 0.4 mm
- Layer height : 0.2 mm
- Infill density : 100%
- Infill pattern : Zig-Zag ±45°

Properties	Data sheet	Pam	Pam performance
Density [g/cm^3]	3.80	3.78	99.36 %
Open Porosity [%]	-	0.64	< 1 %
Flexural Strength (ASTM C1161-18) - [Mpa]	> 370	465,43	-

CRIBC
member of EMRA

The 3D printed ceramic parts have a density superior to 99%.

Use cases

From tooling application to production

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Tooling, jigs and fixtures

Using traditional 3D printers could save 50-75% of costs and reduce significantly lead time

Pam 3D printers saves 91% of the cost of production
and the part is available the same day.

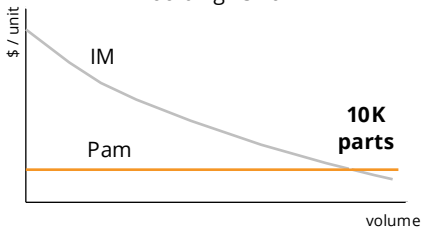
CNC cost/part: **€ 49,58**

New Pam Series P cost / part: **€ 4,56**

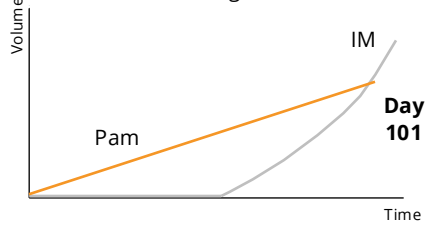
Injection Moulding vs Pam 3D printing

Pam 3D printers are :
- **more cost effective** than IM **up to 10K parts**;
- **more productive** than IM **up to 101 days** after design validation.

Cost per part comparison: injection moulding vs Pam



Production volume comparison: injection moulding vs Pam



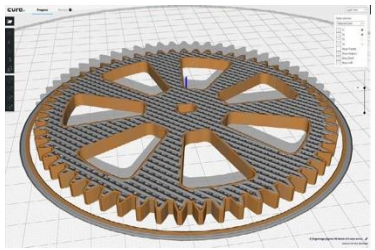
Multi-resolution

Using multi-resolution could save 30-80% of production time while maintaining the aesthetic qualities

using **one 3D printing resolution** with a 0.4 mm nozzle
=
6 hours production time

using **two 3D printing resolutions** combining 0.4 mm & 0.8 mm nozzles
=
3,5 hours production time

+1.7X faster



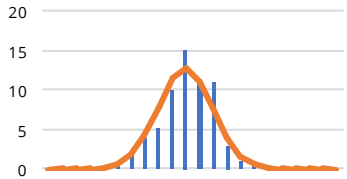
0.4mm nozzle for the outside perimeters (brown)
0.8mm nozzle for the infill (grey)

Production capacities measurements

100 parts produced, 25 per day, using a single Pam 3D printer working 12 hours a day (4 cycles/day, 1 cycle/night);

- Availability rate = 94%
- Performance rate = 99%
- Quality = 100%, no printing failure.

OEE = 93 %, a good setup machine gives outstanding results of productivity thanks to Pam's **reliability and robustness**.



Capability results: Cp = 1,42
Cpk = 1,34

Use case, Printing Proprietary Flame Retardant Polycarbonate [1/2]

Needs, Characterization & Mechanical Testing

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General project needs

Strategic Material

A proprietary material, accounting for **60% of the volume of manufactured parts**, qualified and compliant with industry standards.

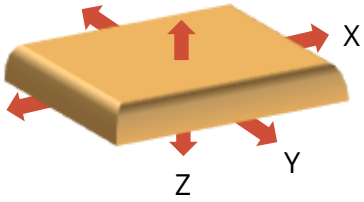
Objective

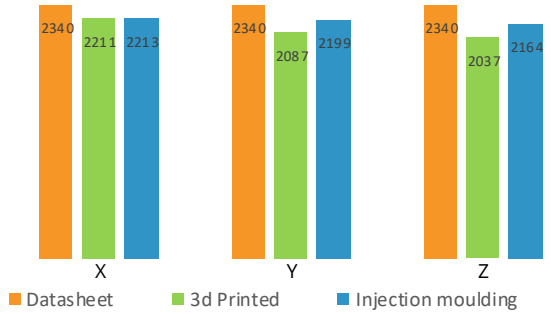
Validate its **processability in pellet 3D printing** to access applications unattainable with injection molding.

Challenges

Maintain mechanical properties and fire behavior while leveraging the advantages of additive manufacturing (geometric complexity, customization, etc.).

Isotropic modulus across the primary directions





Parts were tested in multiple direction to evaluate isotropy

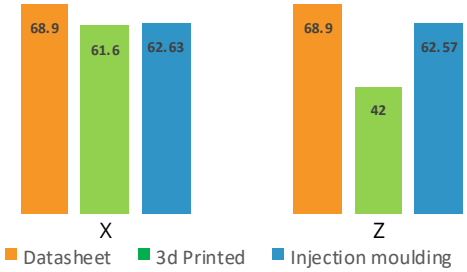
Isotropy would allow to limit overdesign associated with poor performances in Z

	Modulus AM vs IM
X	99.9%
Y	94.9%
Z	94.1%

Comparison of tensile strength

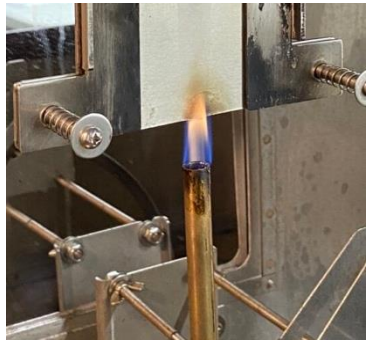
98% tensile strength in X and 64% in Z

Optimal properties **were fully achieved** in X



	Modulus AM vs IM
X	98 .9%
Z	64.7%

Flammability samples were run in external lab



	Vertical burn
IM	Passed
3DP	Passed

Exact same material was processed via injection molding and 3D printing

Flammability performances were recovered hence allowing us to print flammability compliant materials

Use case, Printing Proprietary Flame Retardant Polycarbonate [2/2]

Prevent negative margins on low volumes

Portfolio operate in the negative margin zone

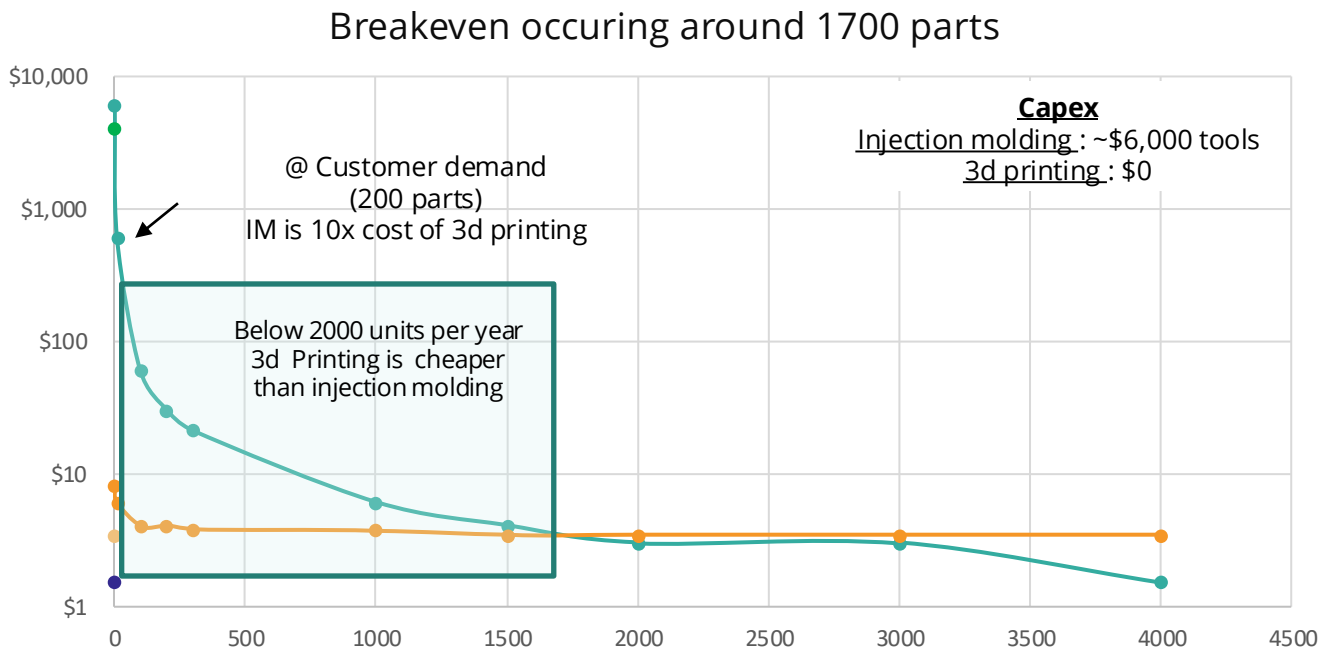
Summary

Customer demand of 200 parts per year.

Assuming minimal margin for injection molding parts the break even will occur around 1700 parts

Gain in lead times are also achieved

- Injection molding – 6-8 weeks
- 3D printing – 1 week



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Filaments chargés en NdFeB pour la fabrication par dépôt de fil fondu

NdFeB gevulde filamenten voor fused filament fabrication

ASTRID DEJOSÉ, GUIDO HEUNEN

CRIBC, 27 January 2026

innovation forward

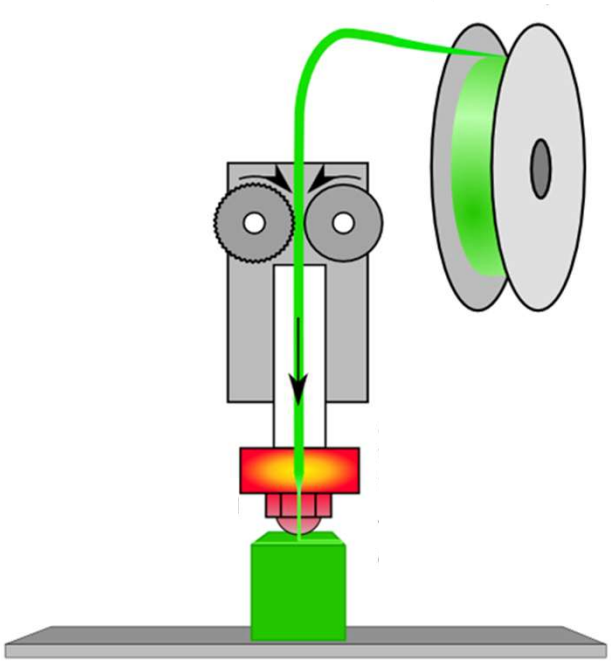
- MW4REAM
  - Recyclage du NdFeB – Hergebruik van NdFeB
  - Recyclage du plastique – Hergebruik van kunststof
  - Réutilisation dans des composites par fabrication additive – Hergebruik in composieten via additieve productie

- Hardmagnet3D
  - Demonstrateur – Demonstrator

- FastAMopt
  - Optimisation des matériaux – Materiaaloptimalisatie

- Tech4Fab DR05
  - MW4REAM Contact avec le groupe cible transfrontalier – Contact met de grensoverschrijdende doelgroep

- FFF / FDM



https://reprap.org/mediawiki/images/2/22/FFF.png

Filaments chargés en NdFeB – NdFeB gevulde filamanten

- Poudre de NdFeB disponible dans le commerce – Commercieel verkrijgbaar NdFeB poeder
  - Sphérique – Sferisch
  - Non-sphérique - Asferisch
- Poudre en PA12 – PA12 poeder
  - Sphérique – Sferisch
- 3Devo Filament Maker One 450
- Elegoo Neptune 3 Pro

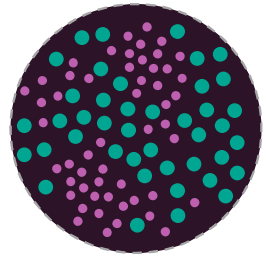
Filaments chargés en NdFeB – NdFeB gevulde filamanten

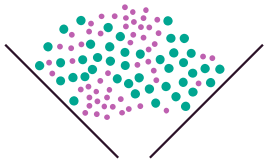
PA12/NdFeB

- NdFeB sphérique – Sferisch NdFeB
- 80-92 % en masse – 80-92 massa %

- NdFeB non-sphérique – Asferisch NdFeB
- 80 % en masse – 80 massa %

- NdFeB sphérique/non-sphérique – Sferisch/asferisch NdFeB
- 80 % en masse d'un mélange 50 % / 50 % en masse –
  80 massa % van een 50 massa % / 50 massa % mengsel



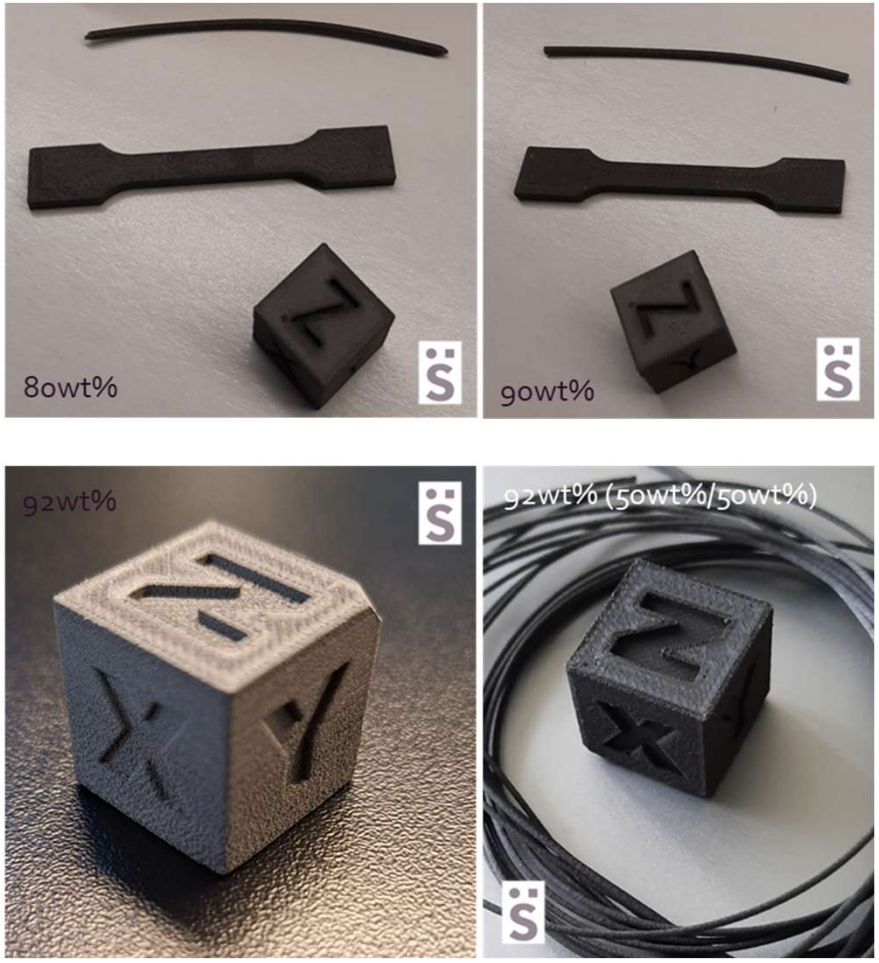


Objets composites par FFF – Composietobjecten via FFF

PA12/NdFeB

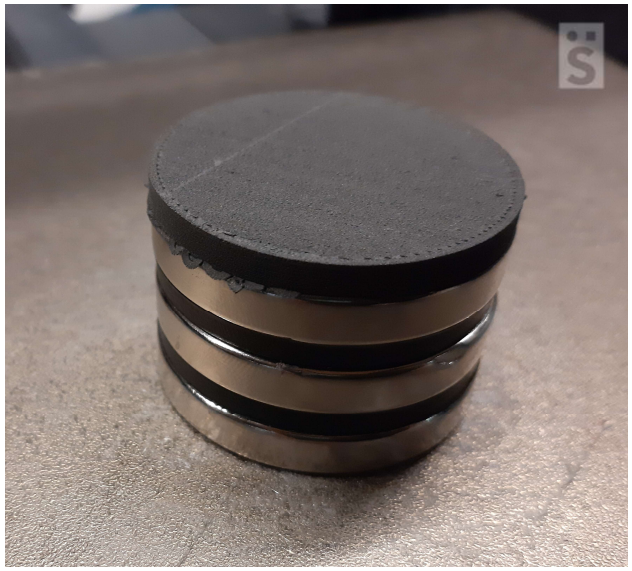
- NdFeB sphérique – Sferisch NdFeB
- 80-92 % en masse – 80-92 massa %

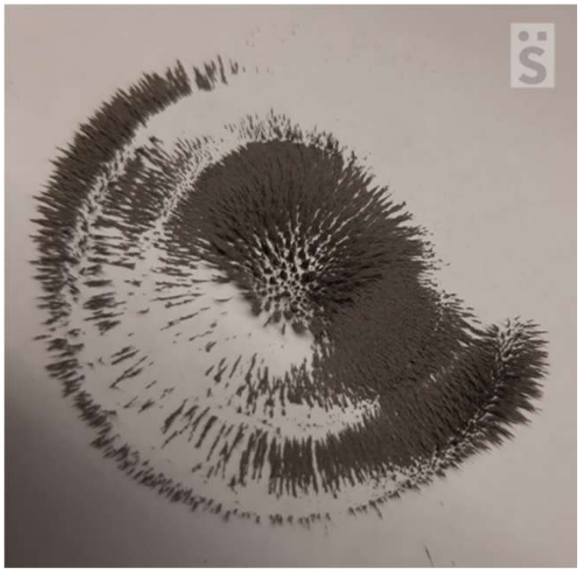
- NdFeB sphérique/non-sphérique – Sferisch/asferisch NdFeB
- 80 % en masse d'un mélange 50 % / 50 % en masse –
  80 massa % van een 50 massa % / 50 massa % mengsel



Magnétisation in situ d'objets composites fabriqués par AM – In situ-magnetisatie van AM-composietobjecten

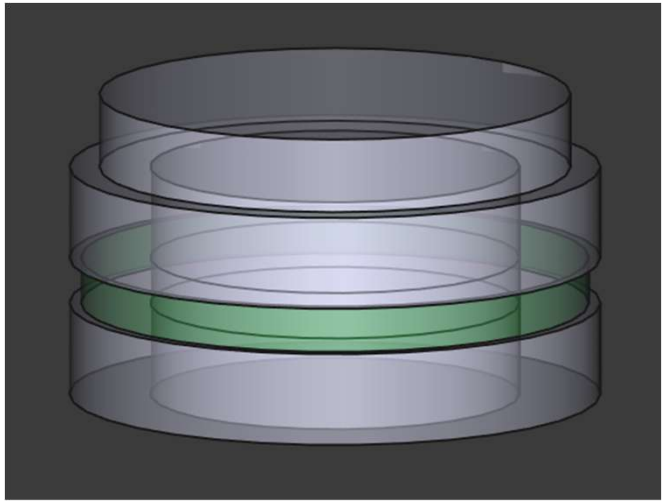
92wt% s-NdFeB

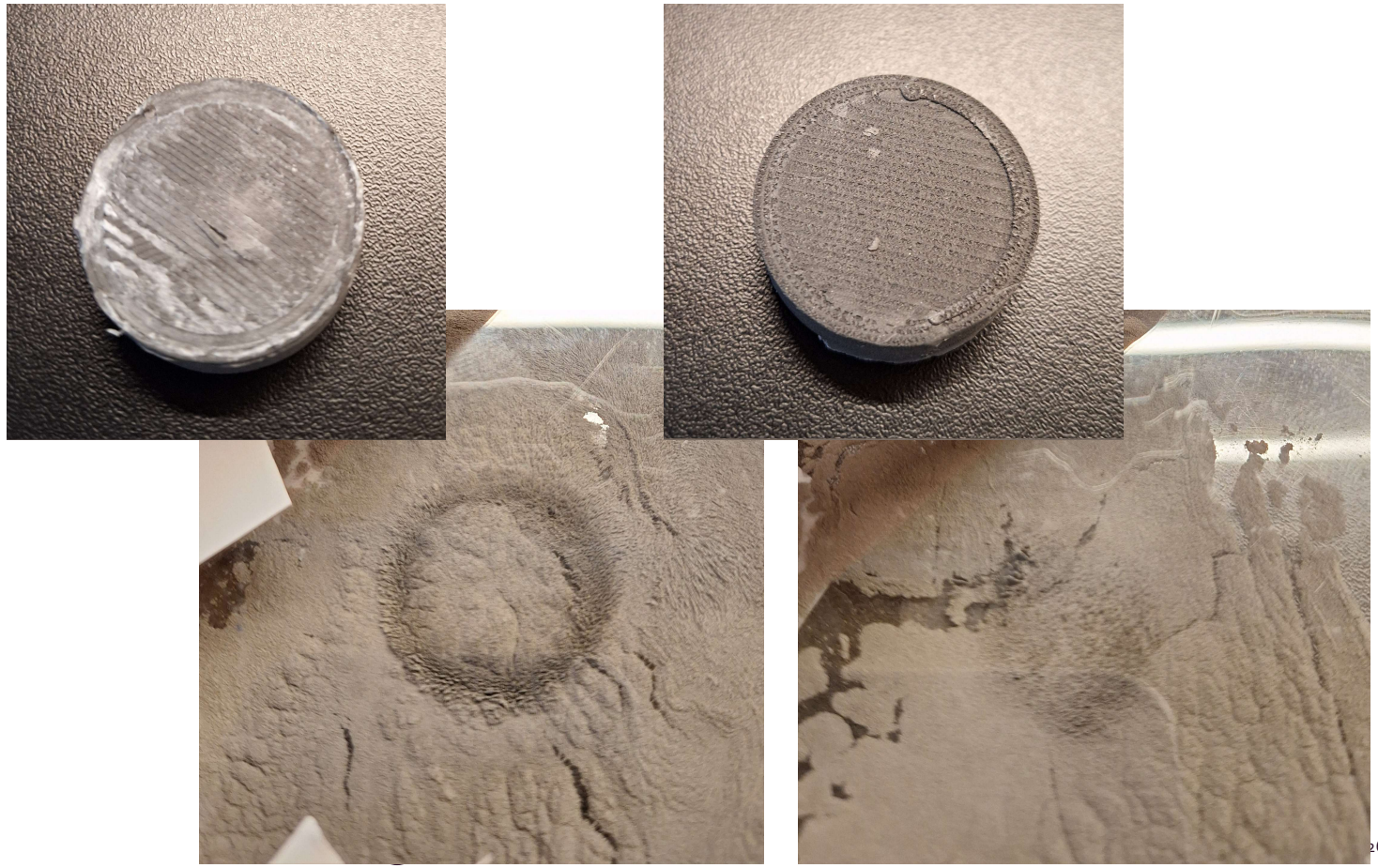




Magnétisation in situ d'objets composites fabriqués par AM – In-situ-magnetisatie van AM-composietobjecten

92wt% s-NdFeB



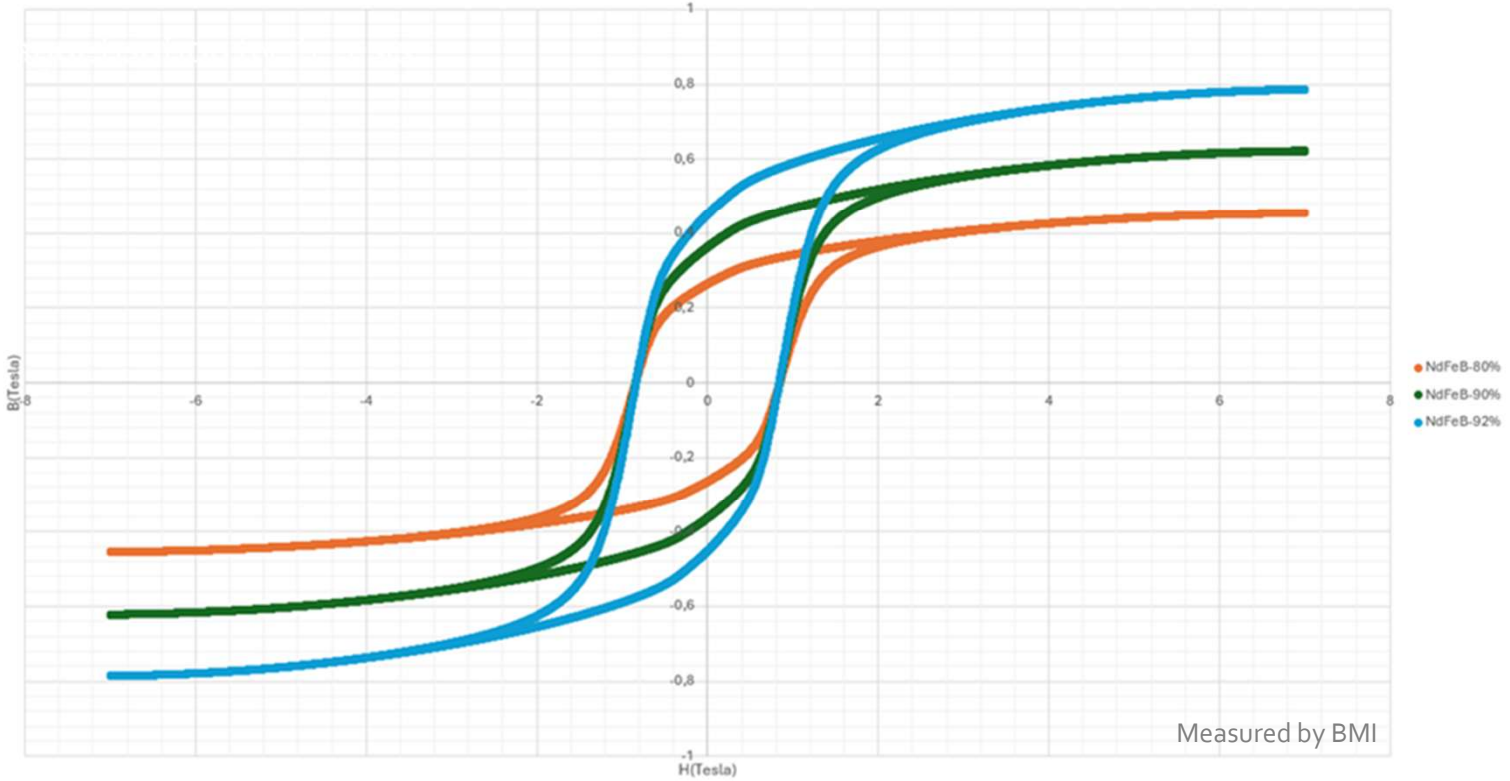


Magnétisation in situ d'objets composites fabriqués par AM – In-situ-magnetisatie van AM-composietobjecten

92wt% s-NdFeB

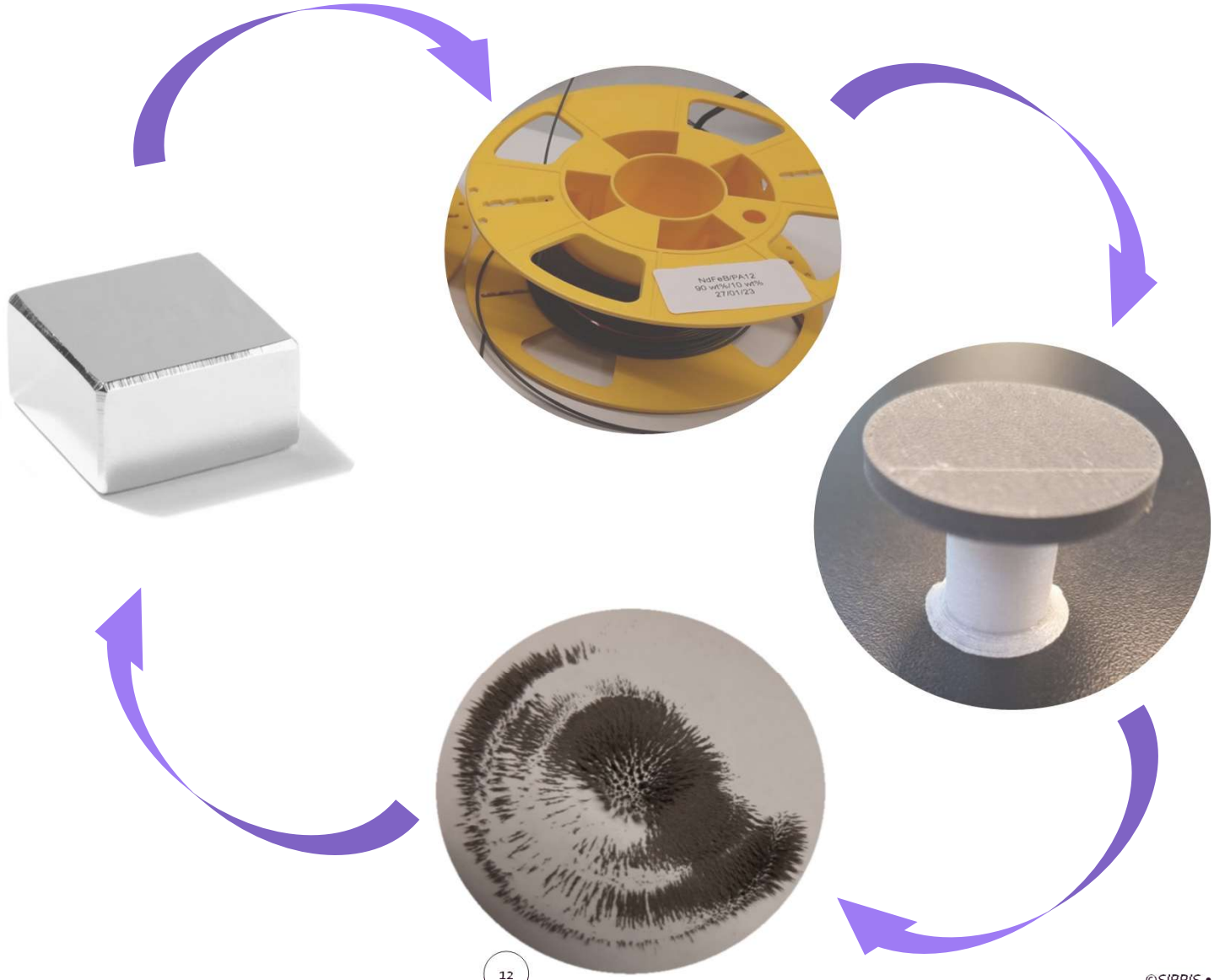
Magnétisation ex situ d'objets composites fabriqués par AM – Ex-situ-magnetisatie van AM-composietobjecten

Hystérésis de magnétisation - Magnetisatiehysterese



Champ rémanent – Remanent veld

- ~425mT (92wt% s-NdFeB)
- ~350mT (Ferrite - Ferriet)
- ~700mT (100% s-NdFeB)
- ~900mT (100% ns/as-NdFeB)


NdFeB/PA12
90 wt%/10 wt%
27/01/23

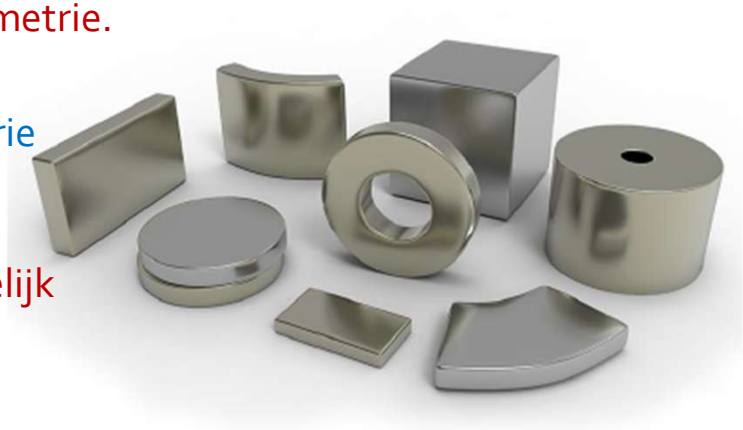
HardMagnet3D

Setareh Gorji Ghalamestani – Thomas Kairet
Astrid Dejosé – Guido Heunen

Démonstrateur d'une machine électrique avec des « aimants liés » fabriqués par AM – Demonstrator van een elektrische machine met via AM vervaardigde « gebonden magneten »

Défis : les aimants frittés disponibles dans le commerce présentent des limitations géométriques.
Uitdagingen: commercieel verkrijgbare gesinterde magneten zijn beperkt in geometrie.

Opportunité : la fabrication additive offre une plus grande liberté dans la géométrie des aimants, ouvrant de nouvelles possibilités pour la conception des machines électriques.
Kans: additieve productie maakt een grotere vrijheid in magneetgeometrie mogelijk en opent nieuwe mogelijkheden voor het ontwerp van elektrische machines.



Setareh Gorji Ghalamestani – Thomas Kairet
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Démonstrateur d'une machine électrique avec des « aimants liés » fabriqués par AM – Demonstrator van een elektrische machine met via AM vervaardigde « gebonden magneten »

Motivation : à des vitesses de fonctionnement élevées, les machines électriques génèrent une quantité importante de chaleur, ce qui peut dégrader les performances si elle n'est pas efficacement gérée.
Motivatie: bij hoge bedrijfssnelheden genereren elektrische machines aanzienlijke warmte, wat de prestaties kan verminderen als dit niet doeltreffend wordt beheerd.

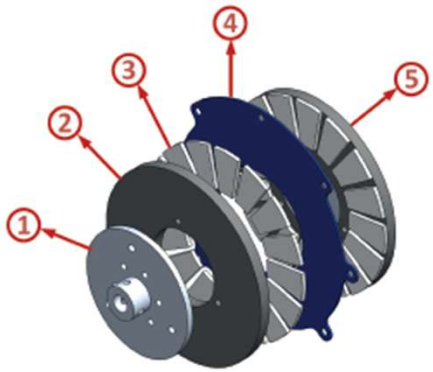
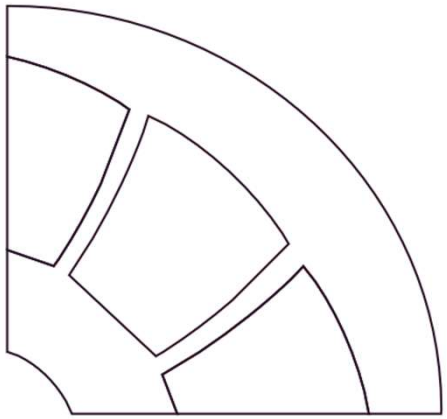
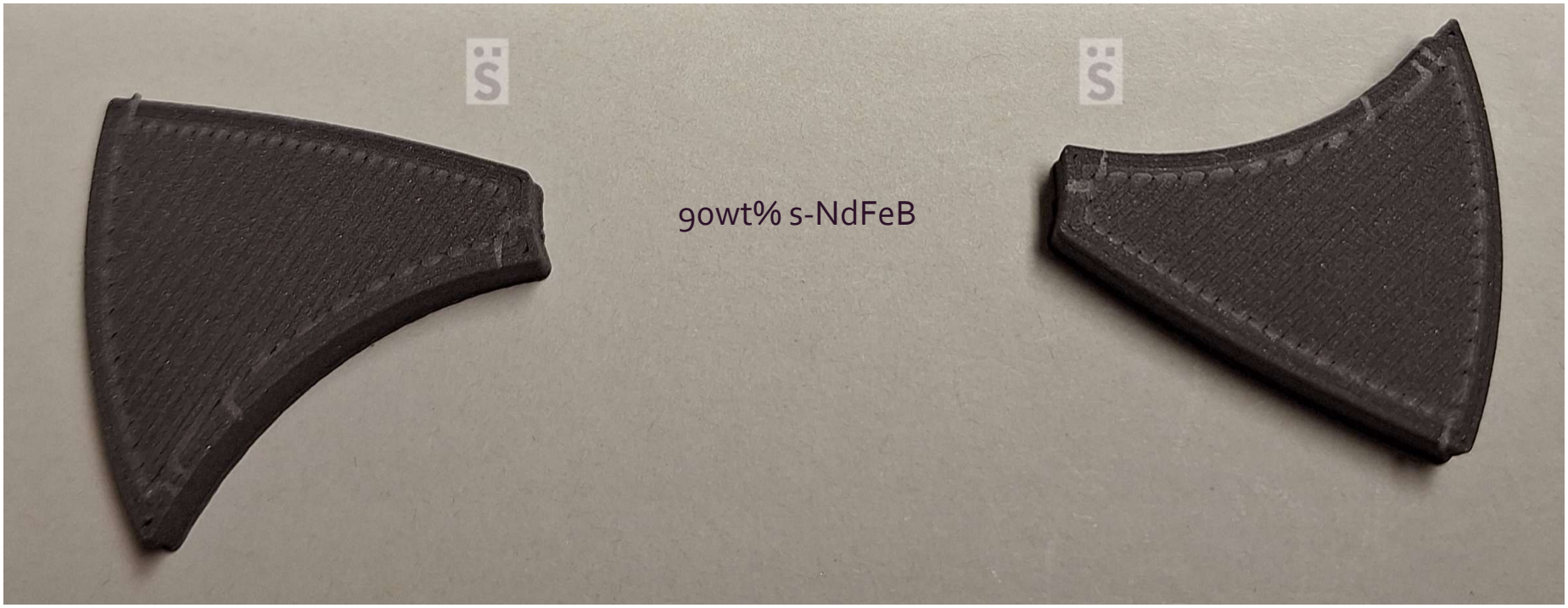


Figure 6: General mechanical design: 1) Rotor cover, 2) Rotor back plate, 3) Magnets, 4) PCB, 5) Second rotor back plate [3]

Objectif : développer un démonstrateur de machine électrique à flux axial utilisant des géométries d'aimants personnalisées par fabrication additive, permettant l'intégration de canaux de refroidissement pour une meilleure dissipation thermique.
Doel: een demonstrator ontwikkelen van een elektrische axiaalflux machine met op maat gemaakte magneetgeometrieën via additieve productie, die de integratie van koelkanalen mogelijk maken voor een verbeterde warmteafvoer.



Magnétisation ex situ d'objets composites fabriqués par AM – Ex-situ-magnetisatie van AM-composietobjecten



Champ rémanent – Remanent veld
- ~340mT

Coercivité intrinsèque– Intrinsieke coerciviteit
- ~681kA/m

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