Micro Injection Molding Technology

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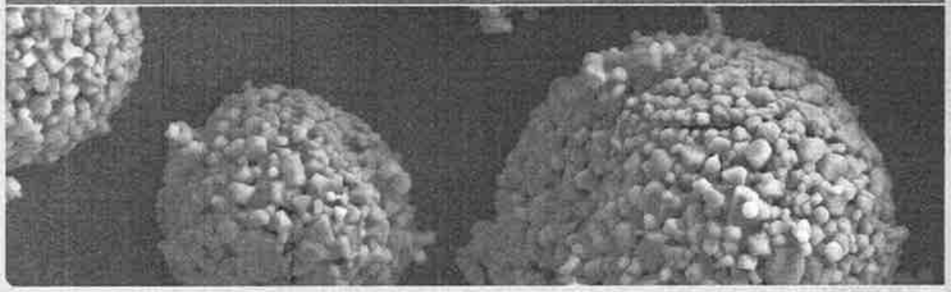

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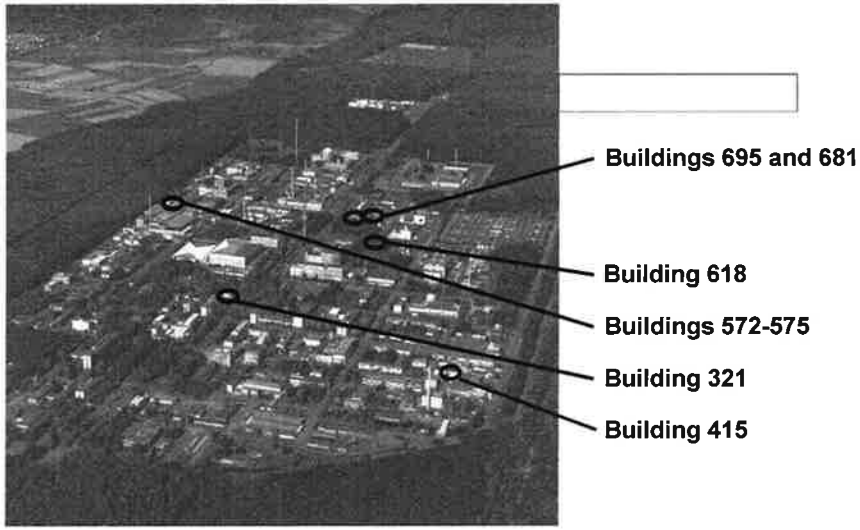


Micro Injection Molding

Contents

- Introduction to Injection Molding
- Introduction to Micro Injection Molding (µIM)
- Metal and Ceramic Micro Components
    - micro powder injection molding (MicroPIM)
- Multi-Component Powder Injection Molding
- Simulation
- Summary and Outlook

Manufacturing of Micro Components

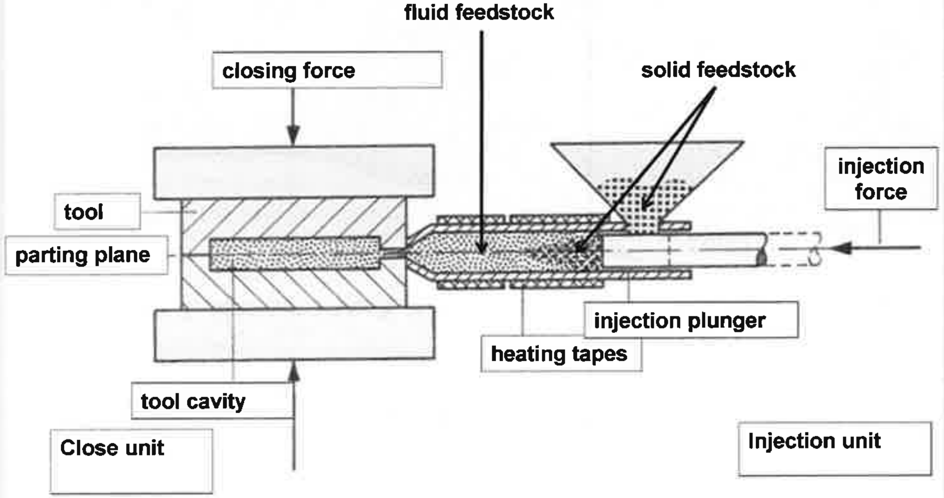
- with **high economic efficiency** depends strongly on number of pieces

    industry > (5000) **10000** pieces p.a.

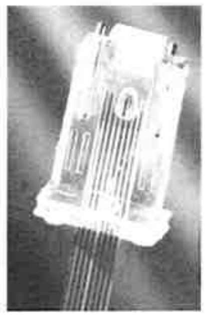
    KIT > **100** pieces p.a.

- in a **wide range of materials** (polymers, metals, ceramics etc.)
- with **smallest structures** in the micro- and nanometer range
- with **high complexity** and **functionality** (multi-component, inmold-labelling etc.)

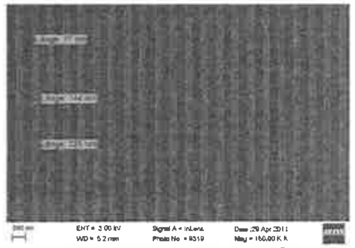
Injection Molding - Principle



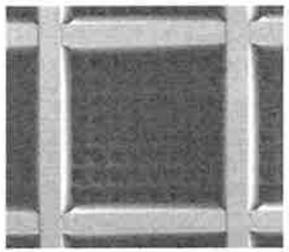
Micro Injection Molding with Polymers



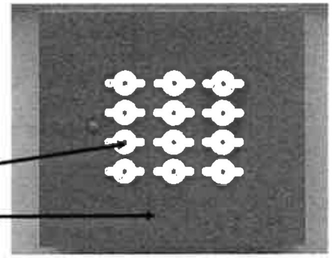
Ribcon® glass fiber connector PMMA, Spinner GmbH



*wall-groove structure for phase contrast microscopy PMMA, **width < 100nm***



bio-containers for cell cultivation, PMMA 30×30 µm²



2C-preforms for galvanic replication, insulating micro structures (POM) on conductive substrate (PA 12)

Micro Powder Injection Molding

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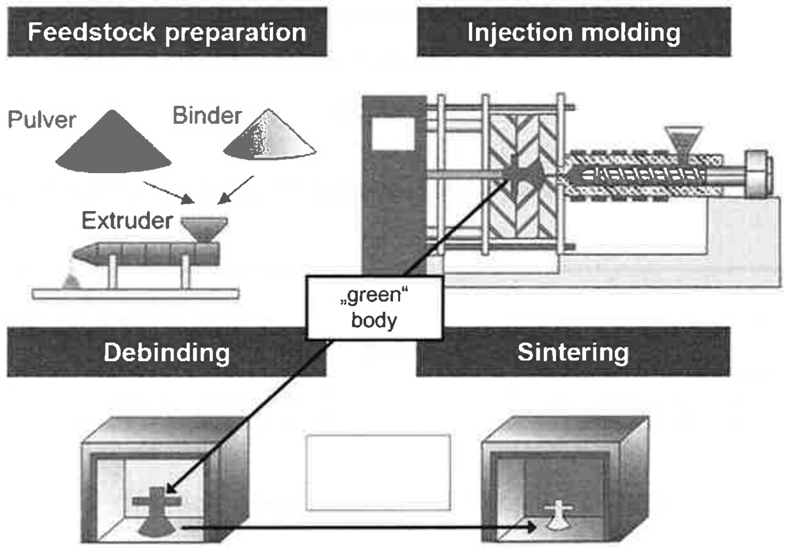


PIM-Materials (selection)

Metal	tempering steel	42 CrMo 4, 40 NiCrMo 6
	case-hardened steel	21 NiCr Mo 2, 16 MnCr 5
	tool steel	100 6W 5Mo 4 Cr 2V
	stainless steel	X20 Cr 13, X6 Cr 17
	austenitic stainless steel	X2 CrNiMo 17 13 2 (316L, 1.4404)
	precipitation hardening steel	X5 CrNiCuNb 17 4 (17-4PH, 1.4542)
	low-alloyed iron	Fe2Ni, FeNi7
	softmagnetic materials	carbonyl-Fe, Fe50Ni, FeSi3
	covar	Fe 29Ni 17Co
	copper	Cu, CuNi50, CuFe
	titanium	Ti6Al4V, TiAl7Nb
	nickel-base alloys	NiCr 22 Fe 18 Mo, NiCr 20 Co 18 Ti
	refractory metals	W, W-La_2O_3, WNiFe, WCu10, MoNb13, Mo20Cu
Hard metals, Cermets	carbides, nitrides	WCxCo, TiN
	cermets	Mo-Al_2O_3, Fe-TiC
Ceramic	oxide-ceramics	Al_2O_3, ZrO_2, ZTA, ATZ
	nonoxide-ceramics	Si_3N_4, SiC, AlN
	functional ceramics	PZT, TiN

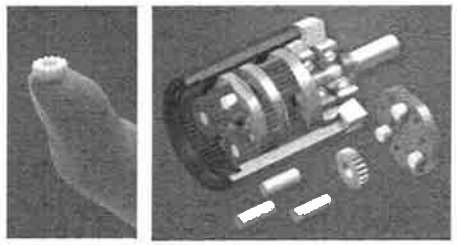
Processible Ceramics - Key Data

	Al_2O_3	Al_2O_3 + TiN	AlN	ZrO_2
melting point [°C]	2050		2150 - 2200	
dintering temperature [°C]	≤1600		1600 - 1900	1350
density [g/cm³]	3.94		3.26	6.06
thermal conductivity [W/(m×K)]	35.6 - 39		180 - 220	2.0
E-modulus [GPa]	406		350	200
bending strength [MPa]	630		300 - 400	600 - 1200
CTE [10^-6/K]	23.8	9,0	4.63	10
electrical conductivity [A/(V*m)]	37.7×10^6		> 10^14	
electrical resistance [mΩcm]		0.15 - 200		10^13

PIM – industrial applications

worldwide market **MIM: ~ 1.000 Mio. US-$**

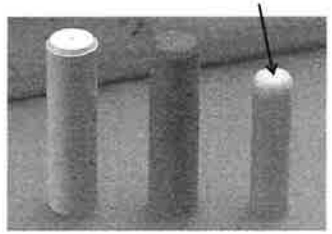
CIM: ~ 400 Mio. US-$



Maxxon Motor GmbH

Bernhard Förster GmbH

hole Ø = 125µm



Krone GmbH

Transparent/Translucent Ceramics

Challenges:

Powders and sintered parts of very **high purity** required

→ suitable feedstocks available

Very **low porosity** necessary

→ appropriate sintering procedures

Grain sizes must be $< \lambda_{light}$ or $> \lambda_{light}$

→ appropriate sintering procedures

Powder Injection Molding (PIM)

Feedstock preparation

MicroPIM - Feedstocks

Contrary demands on MicroPIM powders

contour details and surface quality: powder size as fine as possible	⟷	good flowability and low sintering shrinkage: powder size as large as possible

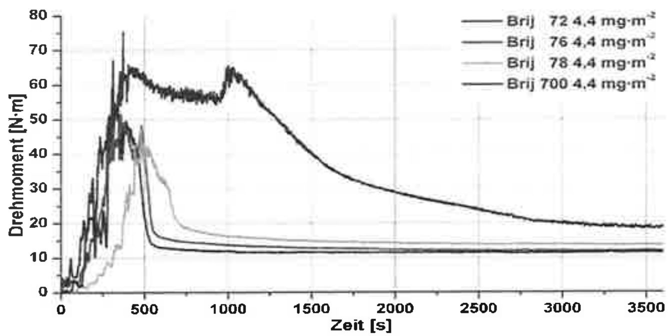
current compromise: particle sizes between 0.2 µm (ceramic) – 4 µm (steel)

Solutions:

- optimized additions of dispersants
- **multimodal mixtures** of nano- and micropowders

Binder optimization using tailored dispersants

Brij 72,76,78,700
Sigma Aldrich



• optimized dispersant content

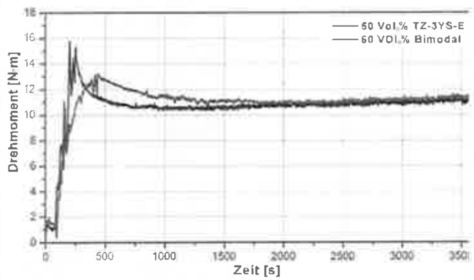
reduced glycole chain length leads to lower energy input and viscosity

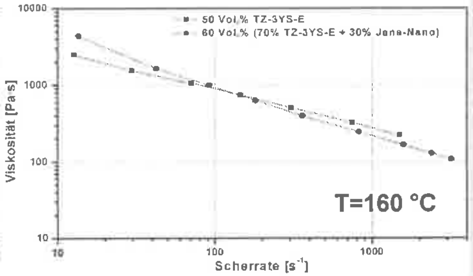
=> increased powder content (≥ 50 Vol.%)

MicroPIM - Feedstocks

Increasing powder content by using bimodal powders

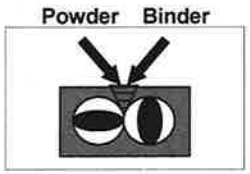
- bimodal: **60 vol.%** powder content (70 % rough + 30 % fine)
- monomodal: 50 vol.% powder content (100 % rough)



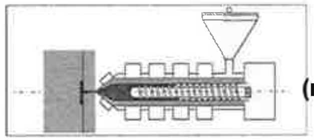


Increasing the powder content from 50 → 60 vol.% while processibility and viscosity remain equal

Powder Injection Molding (PIM)



Feedstock preparation



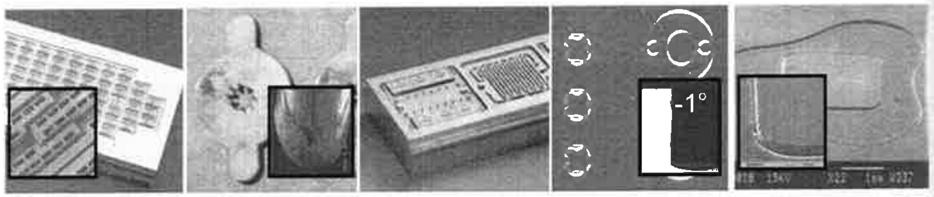
Shaping by (micro) injection molding

17- 4PH

Injection Molding of Micro Components

Inserts for Micro Injection Molding Tools

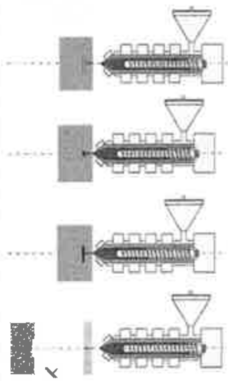
LIGA	SU8	Micro-Cutting	Silicon	Laser



X-ray lithography + galvanoforming	UV-light + galvanoforming	Micro-cutting, -milling, -drilling	Si-etching	Laser-Ablation
Nickel, (Ni-all.)	Nickel, (Ni-all.)	Brass, Steel	Silicon	Steel, HM, Ceramic
+ AR = 20-30	+ ejection slopes	+ ejection slopes	AR = 5	wear resistant
+ R_{max} = 0.04µm	AR = mind. 5	AR = 5-10	- cut-backs	AR = 5 (10)
- time for delivery	- roughness	R_{max} = 0.2 – 0.5µm	- critical	- R_{max} = 2µm

Injection Molding of Micro Components

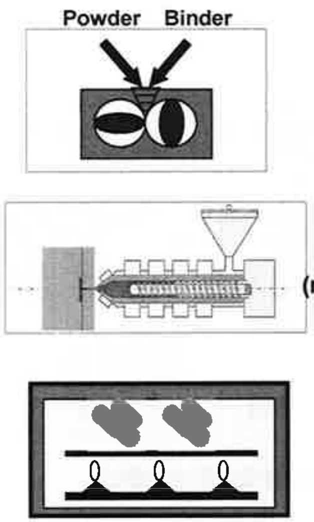
Specialities



- **Closing + Heating of mold core**
  Plastification of feedstock
- **Evacuation of molding tool**
  Injection of feedstock
- **Dwell pressure phase**
  Cooling of molding tool
- **Precise tool movements**
  Ejection and handling

Heating / Cooling = Variotherm-process necessary for replication of high aspect ratios

Powder Injection Molding (PIM)



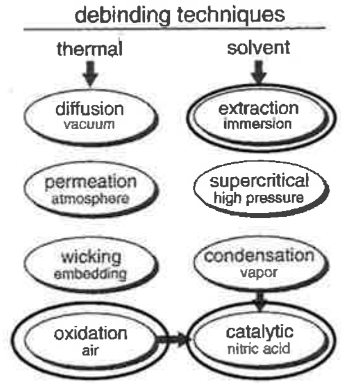
Feedstock preparation

Shaping by (micro) injection molding

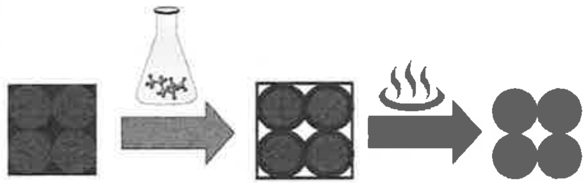
Debinding and sintering

MicroPIM - Debinding

Extraction of the organic binder



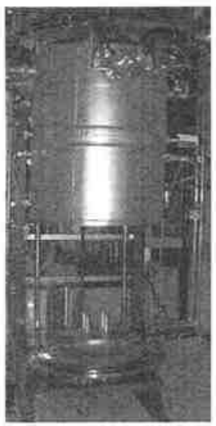
R. German
San Diego SU

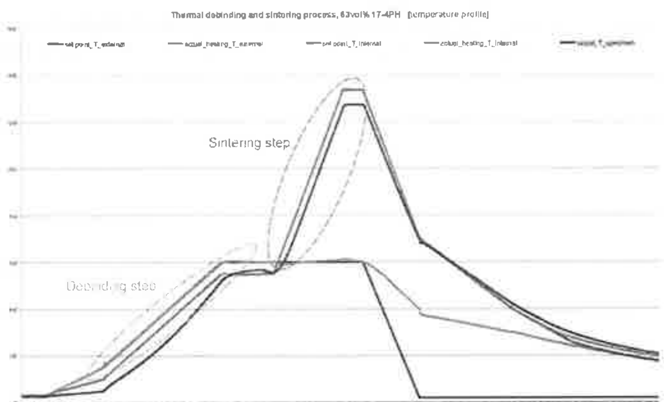


at KIT approved for MicroPIM:

solvent pre-debinding
thermal main debinding

MicroPIM - Sintering

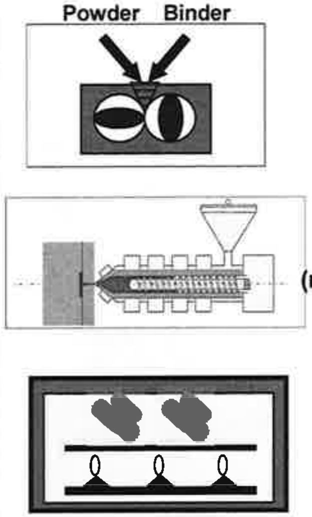




thermal debinding and sintering process
63Vol.% powder, 17-4PH, H_2-atmosphere

- densities of up to 96 – 99% of theo. density achieved
- generation of fine grain sizes by optimized heating- and cooling rates

Powder Injection Molding (PIM)

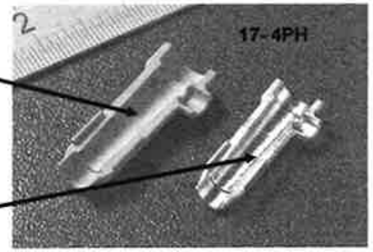


Feedstock preparation

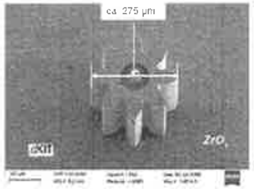
Shaping by (micro) injection molding

Debinding and sintering

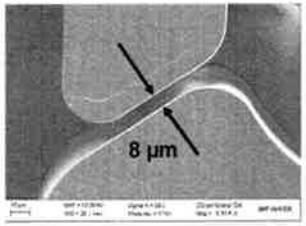
Sinter shrinkage
(15 – 23 % linear)
depending on powder/binder mixing ratio



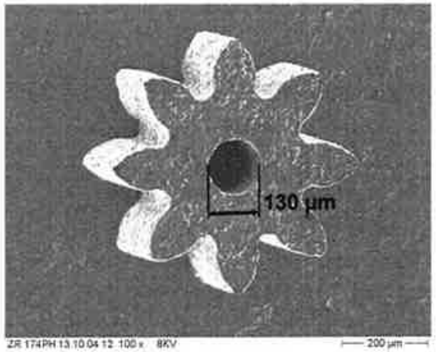
MicroPIM



ceramic gear wheel
outer-∅ approx. 275 µm



turbine channel plate
injection molded with ZrO_2



metal gear wheel
steel 17-4PH (1.4542)
outer-∅ approx. 610 µm

Micro Injection Molding – General Data

Materials	min. lat. Dimension [µm]	min. Detail [µm]	Aspect Ratio [isolated walls]	Tolerance [%]	Roughness ** R_{max} / R_a [µm]	Materials tested
Plastics	10	<0.1	>20 (200*)	± 0.05	0.05 / <0.05	Thermoplastics, TPE
Metals	50	10	>10	< ± 0.5	7 / 0.8	17-4PH, 316L, Cu, W, W-alloys
Ceramics	<10	<3	<15	(± 0.1) ± 0.3	2 / <0.3	ZrO_2, Al_2O_3, ZTA, Al_2O_3/TiN, Si_3N_4

* flow length to wall thickness ratio ** depending on mold insert

Multi-Component Micro Powder Injection Molding

Objectives

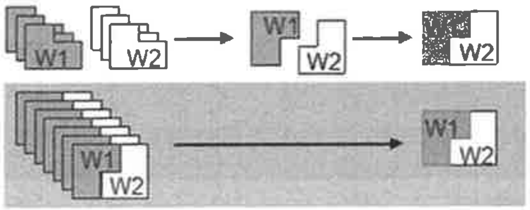
Functions integration by combining different materials

Realization of (im-)mobile connections

Reduction of handling and assembly expenditure

single-piece fabrication + assembly

2C-MicroPIM – assembly



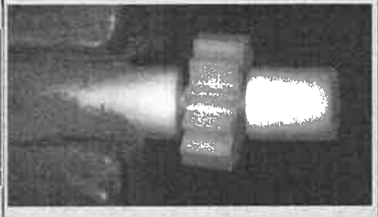
Multifunctional- / Multimaterial Products

with complimentary or contradictionary properties, e.g.

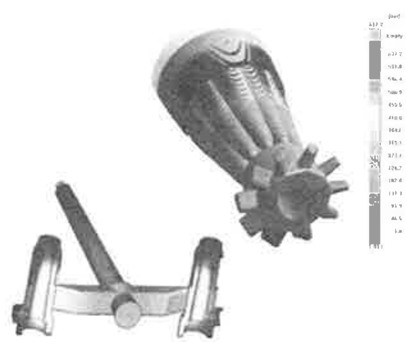
conductive	↔	insulating
hard	↔	tough
magnetic	↔	non-magnetic
hydrophilic	↔	hydrophobic
tight	↔	porous

→ **2-component MicroPIM (2C-MicroPIM)**

2-Component PIM

connection	fixed	movable
binders	compatible	not relevant
powder loading	nearly equal	$\varphi_{outside} > \varphi_{inside}$
sintering-T	nearly equal	$T_{outside} > T_{inside}$
CTE	nearly equal	nearly equal
		

Simulation of (Micro-)PIM



Motivation

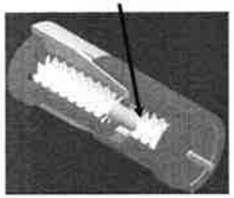
- ❖ avoid re-engineering (micro !)
- ❖ improve producible part design
- ❖ estimation of process parameters

Challenges

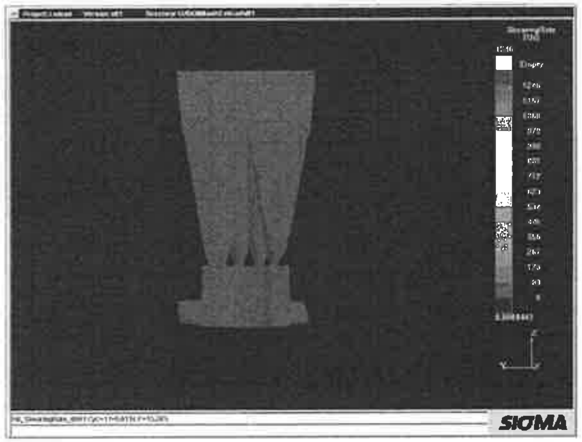
- ❖ commercial software based on one-phase material models
- ❖ powder-binder segregation, inertia effects etc. not considered
- ❖ high surface-/volume ratio (micro !)
- ❖ abrupt changes of cross sections (micro !)

Simulation of (Micro-)PIM

rotor disc of micro combustion turbine



ZrO_2-feedstock (50-Vol%)

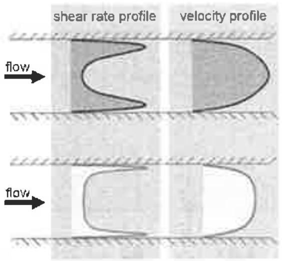


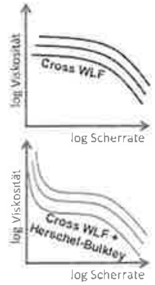
indicates constrictively

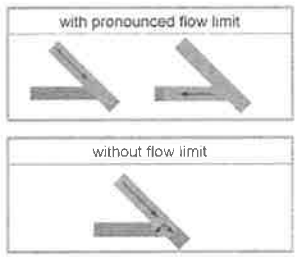
- ❖ shear rates
- ❖ quantitative analysis ?
- ❖ jetting
- ❖ wrinkling

→ **approaches to improve PIM-Simulation necessary**

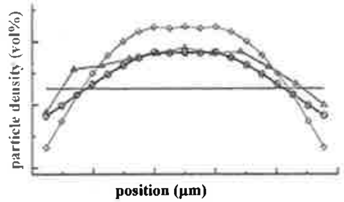
Modified one-phase model (SIGMA Engineering GmbH)
implementation of yield stress/flow limit

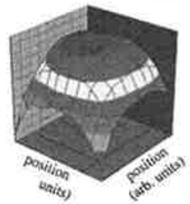






Multi-phase models e.g. Smoothed Particle Hydrodynamics (SPH)





Source:
Smoothed particle hydrodynamics simulation of shear-induced powder migration in injection molding
D. Kauzlaric et al.,
Phil. Trans. R. Soc. A 2011 ***369****, 2320-2328*

Current R+D Activities

- **Improvement of dimensional accuracy and surface quality**
  - influence of dispersants, modified filling process etc.
- **Enhanced multi-component process variants**
  - two-component MicroPIM
  - IML-MicroPIM
  - quasi- gradient materials e.g. W / W-alloys / HT-alloys
- **Simulation of (Micro-) PIM**
  - modified models ↔ multi-phase models

Summary

- **Manufacturing process for micro-sized products**
  - e.g. through holes Ø < 125µm possible
- **Economical viable fabrication**
  - medium and large series in industry
  - also small series (< 5000) at KIT
- **Large variety of materials**
  - Ceramics (ZrO_2, Al_2O_3, and others)
  - challenge: transparent/translucent ceramics
- **Two-component PIM and Co-sintering**
  - joining of two green bodies during sintering

KIT – die Kooperation von Forschungszentrum Karlsruhe GmbH und Universität Karlsruhe (TH)
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Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft

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- All colleagues at KIT

Thank you !

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