From powder to demanding components – titanium and powder metallurgy

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What is powder metallurgy (P/M)?

- Powder
- Shaping
- Consolidation
- Usable product
Why applying powder metallurgy?

- Saving of raw material
- **Homogenous properties** → independent of geometry
- **(Near)-Net-Shape production possible** → no or little post-treatment
- **Variety of materials** → hardly conventionally processable materials
- **Porous structures / foams** → technical and medical purpose
- **Stockkeeping** → one raw material for all geometries
- **Cost reduction** → interesting possibilities for titanium
Possible cost reduction of Ti-products

ore (ilmenite, rutile)
titanium oxide

Kroll-process

Ti-sponge

crushing
pressing
plasma welding

vacuum arc remelting

ingot

forging
rolling
extrusion

casting

P/M techniques
(near-net-shape)

Powder

final product

machining

mill products
rods
bars
sheets
Titanium powders

**Spherical** (GA, PA, PREP)
- Good flowability
- High purity
- Relatively expensive

**Irregular shape** (HDH)
- Bad flowability
- Low to medium purity
- Relatively cheap

„Low-cost powders“
- Irregular shape
- Often porous
- Medium purity

Additional processes
- Spheroidization
Techniques

Semi-finished or pre-formed material

HIP: Hot Isostatic Pressing  SPS: Spark Plasma Sintering  Hot extrusion

www.azom.com  www.tu-freiberg.de

plus conventional machining

etp.uni-hannover.de
Techniques

(Near)-Net-Shape

Powder pressing

www.erowa.com

plus sintering
Techniques

(Near)-Net-Shape with high degree of geometrical freedom

Additive Manufacturing (AM)

Metal Injection Moulding (MIM)

Shaping and consolidation by local melting

Injection moulding plus sintering

www.eos.info
Additive Manufacturing

**Powder bed based techniques**

**SLM:** Selective Laser Melting  
**EBM:** Electron Beam Melting

LENS: Laser Engineered Net Shaping  
LMD: Laser Metal Deposition  
LC: Laser Cladding

[Diagrams of the manufacturing process]

www.ifw-dresden.de
Metal Injection Moulding MIM

**Metal powder**

**Injection moulding** (shaping)

**De-binding**

**Sintering** (consolidation)

**Polymeric binder**
Comparison AM and MIM

AM

- Rapid melting and cooling, fine microstructure
- Anisotropic properties and internal stress, if no additional heat treatment applied
- Spherical powders necessary
- Surface needs post-treatment
- Single part to medium large numbers

MIM

- Sintering, coarse microstructure
- Isotropic properties
- Preferentially spherical powders, but irregular shaped usable
- Smooth surface after sintering
- The larger the number of identical parts the better
P/M titanium - challenges

- Ductile
- Brittle

0.5 wt% 14 wt%
P/M titanium - challenges

Reaction of titanium with oxygen, nitrogen and carbon
- Very strong affinity to these elements
- Very high effect on mechanical properties (strength, ductility)

Rather expensive equipment necessary
- Dedicated facilities highly recommended
- Processing under vacuum and inert gas

Ti-powders are relatively coarse
- Surface roughness after sintering higher than P/M steel
- Limited sintering activity – residual porosity

Relatively expensive powder production
- Methods like water atomization not possible
P/M titanium - challenges

More challenges

- grain growth during sintering
- microstructural changes
- residual porosity

wrought Ti-6Al-4V

sintered Ti-6Al-4V
Example MIM of Ti-6Al-4V

Powder
Ti-6Al-4V ELI (grade 23), O-content typ 0.10 to 0.12 wt%

Yield strength
+ HIP

Plastic elongation

Typical properties
O = 0.22 wt%
N = 0.018 wt%
C = 0.045 wt%
Residual porosity 3.5%

Tensile properties matching standards of wrought material achievable

as-sintered, 1350 °C
sintered + hot-isostatic pressed (HIP), 100 MPa / 915 °C / 2h
Example MIM of titanium-aluminides

Current status: MIM processing of TNB-V5  \(\text{(Ti-45Al-5Nb-0.2B-0.2C (at\%)})\)
MIM Ti-6Al-4V – fatigue behaviour

Alloy modification: addition of elemental boron powder

- Forming of titanium boride particles (TiB)
- Hindrance of grain growth (β-phase)
- TiB working as nucleus for α-phase forming during cooling

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<th>Ti-6Al-4V</th>
<th>Ti-6Al-4V-0.5B</th>
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**Change of microstructure**

- Nearly no lamellae
- Grain size 18 µm

**Endurance limit**

- wrought Ti-6Al-4V
- + HIP
- + 0.5% B

- 400 MPa
- 450 MPa
- 640 MPa
Grain refinement

Adding Yttrium

Ti-6Al-4V

sintered at 1400 °C / 2h

colony size 164 µm
3% porosity

Ti-6Al-4V + 0.2Y

formation of Y₂O₃

colony size 103 µm
3% porosity

Additional effect: scavenging of oxygen

→ low cost powders?
Research & development

Modification of existing alloys

Development of P/M alloys
Summary P/M of titanium

- Several P/M techniques are available and commercially applied
- A variety of powders exists, different in shape, purity and price
- Metal Injection Moulding and Additive Manufacturing offer (near)-net-shape possibilities
- Properties matching standards of wrought material, if properly processed
- Optimization rather easily possible by alloy modification

P/M has a great potential for “low cost titanium”

Current / necessary / interesting research

- Development of robust alloys.
- Grain refinement for optimized mechanical properties (fatigue).
- Strengthening by addition of hard particles (MMCs).
- Scientific understanding of the role of interstitial and other alloying elements.