Metal Powder –
the Raw Material of Future Production

- Introduction and Overview
- Applications for Powder Metallurgy
- Methods & Systems for Powder Production
- Physical and Chemical Properties of Metal Powder
- Economic View
- Summary
Metal Powder the new source of Manufacturing

Additive Manufacturing with 3D Printer will be among the 10 future key technologies *1

Source: *1 Mc Kinsey Global Institute / *2 Steel and Metals Market Research GmbH
Metal Powder the new source of Manufacturing

Development in selected Industries for additive Manufacturing

Special Powder Market requires Spherical Particles, with 15 – 80µm diameter

Typical Materials:
- High Grade Steel
- Tool & Die Steel
- Stainless Steel
- Ni-Base and Ni-Co Base alloys
- Titanium alloys
- Precious Metals

Source: Ernst & Young
Metal Powder, typical Applications

Tools
- High Grade Steel
- Tool & Die Steel

Medical
- Stainless Steel
- Ni- & Ti Base Alloy

Aircraft Industry
- High Grade & Stainless Steel
- Ni-base alloys
- Ti alloys

Automotive Industry
- High Grade Steel
- Ni-base alloys
- Aluminium alloy
- Titanium alloys

Jewellery & Chemical
- Precious Metal
- Special Alloys

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New Processes, Applications and Technologies

Particle Shape of Metal Powders

- Normal Atomization Methods result in irregularly shaped Particles
- Powder made by Inert Gas Atomization is spherical Shape

Processing Technologies

- Metal Injection Molding (MIM)
- Thermal Spraying
- Hot Isostatic Pressing (HIP)
- 3D Printing (Additive Manufacturing and fast Prototyping)

Good flow ability is the Key Facture for near Shape Powder Processing Technologies, which is only given by spherical Particle sizes
3D Print (Additive Manufacturing, fast Prototyping)

- Build a three-dimensional work piece according to specified dimensions and shapes (CAD)

- Metal powder bed as a feedstock, with a high flow ability

- Build of a work piece by selectively melting and solidification in layers of the metal powder

- Selective Laser and Electron Beam Melting are typical melting technology for metal powders

- Typical Powder sizes are
  - Laser System: 15µm < d50 < 45 µm
  - Electro Beam: 55 µm < d50 < 75 µm

- Typical solution
  - X, Y: 43 µm
  - Z: 16 µm

- Important for 3D Print is the flow ability of the Powder.
  Good flow ability is only achievable with spherical powder and narrow tolerances of the particle size

Source of Principle: Extreme Tech Newsletter
3D Print (Additive Manufacturing, fast Prototyping)

Production of complex structures with minimum usage of material

Yield up to 75%

Lowest energy consumption

Mechanical Properties of the work pieces produced by 3D Printing are similar to those produced by Casting and Forging
System for Powder Production

Charging Device
Melting Section
Tundish
Atomization Nozzle
Spray Cone
Powder Tower
Exhaust of inert Gas
Cyclone
Pneumatic Powder Transport Tube
Powder Collection

EIGA/VIGA R&D System
ALD Vacuum Technologies
Materials, Melting Process

Typical Feed Stock

- Any Kind of Material Pieces, Ingots, Powder, Scrap, etc
- High pure Metals like Ni, Cr, Co, Fe and other alloying Elements or Alloys with a strictly defined Composition
- Precious Metal like Gold, Silver Platinum
- Reactive Metals like Titanium, Zirconium

Melting process

- Major Components: MF Power Supply, Induction Coil, Crucible (Ceramics or Graphite, open Coil)
- Induction Melting Process under Vacuum or Inert Gas Atmosphere
- Adjusting of the required chemical Composition, Refining and De-gazing
- Low pickup of non Metallic Elements (H₂, N₂, O₂)

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Hydrogen & Nitrogen content in Vacuum Treatment

Hydrogen and Nitrogen content during Vacuum Treatments
Steel: x38CrMoV5-1 / SKD61

Hydrogen [ppm] before vacuum treatment vs. after vacuum treatment

Nitrogen [ppm] before vacuum treatment vs. after vacuum treatment
Hydrogen in Melting

Sievert Law

\[ a[H] = K[H] \times \sqrt{p(H_2)} \]

- \( a[H] \): H-activity
- \( K[H] \): temp pending equilibrium constant
- \( p(H_2) \): partial pressure of H in gas phase

Example

- Before vacuum treatment: 3,0 – 5,0 ppm (H\(_2\))
- After vacuum treatment: < 1,0 ppm (H\(_2\))
Basics – Hydrogen

Increase Hydrogen Solubility:
Nickel, Iron, Cobalt

Decrease Hydrogen Solubility:
Chromium, Carbon

Depending on the particle size the reactive surface of the powder is 1.000 – 4.000 times higher as in a normal melt

Influence of Moisture: \( \text{H}_2\text{O} + \text{Fe} \rightarrow \text{FeO} + 2\text{H} \)

- Moisture in the air in Siberia: ~ 0.1%
- Moisture in the air in Tropical: up to 3%

Source: Sieverts: Zur Metallkunde Band. 21 (1929) S.37-46
Atomization & Process Parameters

- Pouring of the melted and refined Metal into the Tundish with Orifice
- Typical Outlet Diameter typically 3-8 mm
- Atomization of the melt stream via Gas Nozzle System below the Tundish, Solidification of the produced Micro Droplets in the Powder Tower
- Typical Flow Rate: 7 – 30 kg/min
- Gas Pressure: 15 – 100 bar
- Gas Flow Rate 20 – 70 m³/min
- Atomization Gas: Argon or Nitrogen
- Particle size 15 to 80 µm
Powder Properties & Particle Sizes

- Powder particle size distribution is described by lognormal, Gauss, distribution
- Important Reference Values are $d_{50}$ and Standard Deviation ($\sigma$) with
  \[ \sigma = \frac{d_{84}}{d_{50}} = \frac{d_{50}}{d_{16}} \]
- Typical $d_{50}$ is $15 \mu m \leq d_{50} \leq 100 \mu m$
- Target is it to have a narrow distribution of the particle sizes. The long term experiences shows:
  \[ 1.40 \leq \sigma \leq 2.40 \]
- Many technical applications require sieving of the powder after atomization, usable Yield 50-100%
- The morphology of the powder produced with inert gas atomization is spherical.
Control of the Particle Size

The most deciding Parameters for the Particle Size are:

- Flow rate of the metal at the melt outlet $m'_m$
- Pressure of the Atomization Gas in the Nozzle $p_D$
- Temperature of the Atomization Gas $T_p$

### Parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_s$</td>
<td>static pressure melt chamber</td>
<td>Pa</td>
</tr>
<tr>
<td>$p_T$</td>
<td>static pressure tower</td>
<td>Pa</td>
</tr>
<tr>
<td>$P_{s:s}$</td>
<td>Sum of stagnation and sucking pressure of the nozzle measured directly at exit</td>
<td>Pa</td>
</tr>
<tr>
<td>$h_m$</td>
<td>Level pouring cup</td>
<td>m</td>
</tr>
<tr>
<td>$p_m$</td>
<td>met allostatic pressure of pouring cup</td>
<td>Pa</td>
</tr>
<tr>
<td>$d_m$</td>
<td>Diameter melt at exit</td>
<td>m</td>
</tr>
<tr>
<td>$p_D$</td>
<td>static atomization pressure in the nozzle chamber (pre-pressure)</td>
<td>Pa</td>
</tr>
<tr>
<td>$T_p$</td>
<td>Temperature of the atomization Gas</td>
<td>K</td>
</tr>
<tr>
<td>$A_D$</td>
<td>Area of the nozzle outlet</td>
<td>m²</td>
</tr>
<tr>
<td>$\rho_m$</td>
<td>liquid density of the metal</td>
<td>kg / m³</td>
</tr>
<tr>
<td>$v_m$</td>
<td>exit speed of the melt (at melt exit position)</td>
<td>m / s</td>
</tr>
<tr>
<td>$m'_m$</td>
<td>flow rate of the metal at the melt outlet</td>
<td>kg / s</td>
</tr>
</tbody>
</table>

### Equations

1. $p_m = \rho_m \cdot g \cdot h_m$
2. $v_m \propto \sqrt{2 \cdot (p_s - p_T + P_{s:s} + p_m) / \rho_m}$
3. $m'_m = \rho_m \cdot d_m^2 \cdot \pi / 4 \cdot v_m$
Economical View

Powder Production Process

- The design of a separate melt chamber allows short evacuation times, this increases the productivity
- Vacuum charging device set the evacuation time to zero
- The high pressure nozzle design reduce the inert gas consumption to 1.7 – 2.3 m³ Nitrogen or Argon for each KG of metal powder
- Reduction of the costs from 90 USD/kg in 2013 to level of 30 USD/kg in 2020

3D Printing Process

- Increase of the print speed from 10cm³/h to 80cm³/h in 2020
- Reduction of the post processing from 90 minutes/kg to 50 minutes/kg
- Less than 50% of the energy consumption (and costs) compared to machining
- Best Yield on raw material, means reduced scrap

- The additive manufacturing process has no need for any design and making of moulds or tools. This reduces the costs significantly
Summary

- Additive Manufacturing is one of the Key Technologies of the future
- Complex forms could be produced without any costs for mould or tools
- Productivity increases permanently
- Immediate Prototyping, just a CAD file is required
- Exact fitting medical implants (artificial hip, teeth, knee) will be possible
- Future Application in Aircraft Industry will be the driving forces
- Only Spherical Powder can fulfill the demanding Requirements
- Spherical Powder is available for all Steel Alloys, Nickel based Alloyed, Super Alloy and for Titanium and Ti Alloys, other reactive Materials like Zirconium, Hafnium, etc. As well as precious Metal

There are a lot of discussion and opinions about Industry 4.0.

This is Industry 4.0
Thank You for Your Attention

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