Primary shaping - Casting

Manufacturing Technology II
Lecture 1

Laboratory for Machine Tools and Production Engineering
Chair of Manufacturing Technology

Prof. Dr.-Ing. F. Klocke

Structure of the lecture Casting

Introduction: Variety of applications
Basics of casting
Production sequence at casting
Production of casting patterns
Production of consumable moulds and cores
Casting processes
Case studies: Simulation during design and production
Case study: Rapid-Prototyping used at production of casting patterns
Comparison of costs
Summary
Structure of the lecture Casting

- Introduction: Variety of applications
  - Survey of materials for casting and application examples
- Basics of casting
- Production sequence at casting
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Survey of materials for casting

- **Ferrous materials**
  - Technical pure iron (C < 0.1%)
  - Steel (0.1% C < 2%)
  - Cast iron (2% < C < 4.5%)
  - White cast iron
  - Annealed cast iron
  - Grey cast iron
  - Lamellar
  - Globular

- **Nonferrous materials**
  - Copper
  - Aluminium
  - Others (magnesium, tin, etc.)
Sun wagon - Early bronze period

The golden sun wagon of Trundholm, Seeland

Trundholm, Højby, Holbæk, Dänemark
14th cent. b. chr. bronze and gold
length: 59.6 cm

source: Nationalmuseum, Kopenhagen

Production of high-volume components through casting

Abrasive blasting process of a 16-cyl.-motor unit made of GJL-300 (CrCu-alloyed) in a completely encapsulated sand blast chamber with dust extraction set

source: Siempelkamp, Krefeld, konstruieren+giessen 3/94
Production of small-volume components through casting

Precision casting component for an surgical instrument
material: G-X 10 CrNi 18 8 (1.43.12)
dimension: Ø 7 x 54 mm
weight: 10 g

source: Hitzbleck

Prototype of a cast car door made of magnesium

process: magnesium diecasting
material: EN-MC MgAl6Mn
thickness of walls: 2 - 2.5 mm
weight: 3.5 kg

source: Honsel
Motor unit- AUDI 059 2.5 L TDI: Audi A6, A4, A8, Passat

Cast part  Part with machined surfaces

source: Eisenwerke Brühl

Boeing Instrument Panel - Aluminium investment casting

Dimensions
1700x600x1200 mm

source: Titai
Structure of the lecture Casting

Introduction: Variety of applications
- Basics of casting
  - Cooling down the liquefied material
  - Crystallization and crystal growth - directional solidification
  - Basics of solidification
  - Casting simulation: Example

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Cooling down the liquefied material: Changing crystal lattice

Cooling curve of pure iron resp. Fe-C (723°C)

Elementary cell of the crystal system

Body-centered cubic (b.c.c.)
- α- and γ-iron

Face-centered cubic
- δ-iron

source: Verlag Moderne Industrie - Temperguss
Crystallization and crystal growth

- Crystallization nuclei
  - art-own nuclei
  - foreign nuclei (e.g. contamination)

Crystal growth

- no. of nuclei
- rate of cooling
- direction of heat-removal
- crystal size, crystal form

Crystal growth 180° opposite to the heat-removal

Formation of cast structure through crystallization

- Crystal nuclei are uniformly distributed
- Primary nucleation at side walls
- Transition between both extreme examples

- exclusively globulites
- exclusively fringe crystals
- fringe crystals + globulites

source: Spur, Handbuch der Fertigungstechnik, S. 60
Directional a. monocrystalline solidification at turbine blades

- Globulitical solidification
- Fringe crystal solidification
- Monocrystalline solidification

Schematic cast structure

Source: Thyssen

Cast structure after polycrystalline and directional solidification

1. Polycrystalline

2. Directional solidification
Cast structure after monocrystalline solidification

3. monocrystalline solidified

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Grain size in the cast structure - Coarse grain and fine grain

<table>
<thead>
<tr>
<th>number of nuclei</th>
<th>rate of cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>formation of coarse grain</td>
<td>formation of fine grain</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>directional dependance</th>
<th>tensile strength</th>
<th>deformation resistance</th>
<th>hardness</th>
<th>creep rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>coarse grain</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>fine grain</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Solidification of a hypoeutectique alloy

Legend
- a: alloying composition
- b: primary crystallization
- c: eutectic crystallization
- d: eutectic alloy

source: Spur, Handbuch der Fertigungstechnik, S.60
Solidification process - Crystallization at side walls

**Exogenous solidification**

- Smooth wall solidification
- Rough wall solidification
- Sponge like solidification

Example: pure metals

Increase of alloy content

Source: Engler, in Spur, Handbuch der Fertigungstechnik, S.61

Solidification process - Crystallization inside the melt

**Endogenous solidification**

- Pulpy solidification
- Shell forming solidification

Source: Engler, in Spur, Handbuch der Fertigungstechnik, S.61
Wall movement during solidification of cast iron

<table>
<thead>
<tr>
<th>Interface between metal and force</th>
<th>konvex</th>
<th>concave</th>
<th>planar</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial state</td>
<td><img src="image1" alt="a" /></td>
<td><img src="image2" alt="b" /></td>
<td><img src="image3" alt="c" /></td>
</tr>
<tr>
<td>side wall movement</td>
<td><img src="image4" alt="d" /></td>
<td><img src="image5" alt="e" /></td>
<td><img src="image6" alt="f" /></td>
</tr>
<tr>
<td>metal wall movement</td>
<td><img src="image7" alt="g" /></td>
<td><img src="image8" alt="h" /></td>
<td><img src="image9" alt="i" /></td>
</tr>
</tbody>
</table>

Legend: a: die cavity  b: die  c: liquid metal (arrows show the direction of the movement)

Source: Spur, Handbuch der Fertigungstechnik, 9. 75

Casting properties - shrinkage cavitation

- mould filling capacity
- fluidity
- feeding capacity
- heat checking
- Shrinkage cavitation

Shrinkage behaviour of pure metals and eutectic alloys

Shrinkage behaviour of non-eutectic alloys
Basic equations of heat and mass transfer

mould filling  equation of continuity:
\[ \text{div}(\rho \cdot \vec{v}) = 0 \]

Navier-Stokes-equation:
\[ \rho \cdot \vec{v} + \vec{v} \cdot \text{div}(\rho \cdot \vec{v}) = \rho \cdot \vec{g} + \text{grad}(p) + \mu \cdot \Delta \vec{v} \]

solidification  heat transport:
\[ \rho \cdot c_p \left[ T + \vec{v} \cdot \text{grad}(T) \right] = \text{div} \left[ \lambda \cdot \text{grad}(T) \right] + Q \]

with
\[ \rho = \text{density} \quad \mu = \text{kinetic viscosity} \]
\[ p = \text{pressure} \quad c_p = \text{specific heat} \]
\[ \vec{v} = \text{velocity} \quad T = \text{temperature} \]
\[ g = \text{gravitation} \quad \lambda = \text{thermal conductivity} \]
\[ Q = \text{source of heat} \]

source: konstruieren+gessen 23 (1998) Nr. 3

Contribution to casting simulation - Cast part

source: Magma
Contribution to casting simulation - Simulation of mould filling

Structure of the lecture Casting

- Introduction: Variety of applications
- Basics of casting
  - Production sequence at casting
    - Classification according to DIN 8580
    - Definitions of moulding and casting processes
    - The route to the structural cast part
- Production of casting patterns
- Production of consumable moulds and cores
- Casting processes
- Case studies: Simulation during design and production
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Classification of primary shaping methods acc.

Primary shaping

- Primary shaping out of the gaseous or vapour state
  - casting in consumable moulds
    - permanent patterns
    - consumable patterns

- Primary shaping out of the liquid, pulpy or paste like state
  - casting in permanent moulds

- Primary shaping out of the ionized state through electrolytical deposition

- Primary shaping out of the solid, granular or powdery state
  - powder metallurgy

Definitions: Moulding and casting processes

- moulding process: all processes for the production of consumable moulds, which are necessary for the absorption of the liquid metal

- casting process: principle of mould filling, e.g. gravity casting, pressure diecasting, ....
  - static casting (gravity casting)
  - dynamic casting
    - movement of the mould
      - centrifugal casting
    - movement of the melt
      - pressure die casting
    - movement of the mould and melt
      - continuous casting

source: DIN 8550

source: Spur
Structure of the lecture Casting

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The route to the structural cast part

Legend:
- a: cast pattern
- b: hand moulding
- c: machine moulding
- d: core setting
- e: core moulding
- f: setting the top box of the mould
- g: casting
- h: melting
- i: shaking out
- j: casting cleaning room
- k: machining of cast part
- l: shipping
- m: sand bunker
- n: sand plant

Source: Spur
Example of application: Moulding shop

Example of application: Hand core moulding
Example of application: Automatisation at core production

unloading the cores out of the core shooter  

core setting

source: Laempe

Example of application: Machining of cast parts

machining  
deep-hole drilling

source: Gießerei Fronberg
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Tasks of casting pattern - pattern-material requirements

production of consumable moulds
production of permanent moulds
generation the most important outer sections of the die cavity including core marks as well as casting and feed system
setting of core marks for fixing the cores (necessary for cast parts with cavility)

pattern-material requirements

- resistance against
  - mechanical stress (compression, beat loose, unloading the model)
  - chemical stress (humidity, acids and bases of the binding agents, gases)
  - thermal stress (heating of the model plate - necessary for hardening of the moulding material)
- good machinability
- high surface quality
- low density
Production of a metal mould

Drawing of gearbox case cap

Milling a component of the casting pattern

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Summary
Classification of methods for producing consumable moulds

<table>
<thead>
<tr>
<th>mould category</th>
<th>pattern</th>
<th>mould cavity</th>
<th>consumable pattern</th>
<th>compression</th>
<th>moulding method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>permanent moulds</td>
<td></td>
<td></td>
<td></td>
<td>split one piece</td>
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<tr>
<td></td>
<td>hollow</td>
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<td></td>
<td></td>
<td>mechanical</td>
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<td>chemical</td>
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<td>physical</td>
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<td>hollow</td>
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<td>chemical</td>
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<td>solid</td>
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<td>physical</td>
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</tr>
</tbody>
</table>

Overview of mould materials for consumable moulds

- **Granular basis moulding material** (e.g. silica sand)
- **Bond clay additives**
- **Water**
- **Clay-bonded moulding materials** 62%
- **Moulding method**
- **Greensand method**
- **Dry-moulded casting**
- **Chamotte moulding method** (burning process at 600-800°C)
- **Resin-bonded moulding materials, heat-curing** 4.6%
- **Water glass bonded moulding materials** 20%
- **Resin-bonded moulding materials, cold-curing** 19.5%
- **Cement-bonded moulding materials** 12%
- **Others** 5%

Source: Spur
Terminology of mould materials for consumable moulds

- **basis moulding materials**: e.g. quartz sand, zircon sand
- **moulding material binder**: e.g. silicates, artificial resins
- **moulding material additives**: e.g. dust coal and synth. glance coal agent to reduce the wettability

**moulding materials**
(classification acc. to binder type)
e.g.: clay- or water bonded sand

**moulding method**
classification according to technology,
e.g. greensand method, (cold-box) and hot-box method

**part of a mold**
e.g. core, top and bottom box of a mold, shell

- **moulding adjuvants**: e.g. moulding powder, core binder
- **mould coating materials**: e.g. blackening, mould varnish
- **moulding accessories**: e.g. central gate, cooling fixture

**final mould**

source: Spur

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Production of sand moulds using the SEIATSU™-process

**principle**
SEIATSU™ Airflow Squeeze technology

**example of application**: cast part

Process characteristics:
The loose moulding sand is filled into the mould area formed by pattern plate/pattern bolster, mould box and filling frame. An air current is passed through and then the mould is compacted. The air current flows through the sand from the back of the mould in the direction of the pattern and escapes through vents in the pattern plate. The air current moves the sand into the less accessible regions of the pattern and greatly improves and optimises compaction. The final strength in the mould is built up in an after-pressing stage, using a fixed or a flexible pressure plate, a water cushion or a multi-platen press. The magnitude of the press pressure, as well as the pressure and duration of the air current can be controlled. This enables optimum mould strengths to be achieved to suit the individual application.

source: HWS – Heinrich Wagner Sinto
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Core production using cold-box method

The cold-box process is a core production method, at which humid, pourable moulding material is cured (baked) in very short times at room temperature in cold core boxes.

source: Spur
Core production using hot-box method

- core sand dressing
- transport of core sand to the core shooting machine
- core shooting in heated core box
- curing of moulding material in hot die
- unloading the core
- post-cure

Legend:
- a: from the generator
- b: outgoing air into exhauster or in open air
- c: exhauster
- d: core
- e: core box

Examples for hot-box cores on furan resin basis

- single cores and assembled cores for an aluminium suction system of a 6-cylinder injection engine

Source: Spur
Cores and machining allowance at cast part

one piece core

machining allowance

unmachined cast part with core

finished cast part

source: Heidenreich & Harbeck

Structure of the lecture Casting

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Production of consumable moulds and cores

Casting processes
- Casting in consumable moulds with permanent patterns
- Survey of different processes
- Sand casting process
- Shell casting process
- Casting in consumable moulds with consumable patterns
- Casting in permanent moulds without patterns

Case studies: Simulation during design and production
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Summary
### Survey: Casting in consumable moulds with permanent patterns

<table>
<thead>
<tr>
<th>Process</th>
<th>Hand moulding</th>
<th>Machine moulding</th>
<th>Shell casting</th>
<th>Shaw-process</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Possible materials</strong></td>
<td>all metals</td>
<td>all metals</td>
<td>all metals</td>
<td>all metals</td>
</tr>
<tr>
<td><strong>Weights (mass) rough values</strong></td>
<td>no restriction, available transportation equipment and melting capacity determine the upper limit</td>
<td>up to several tons, restricted by the size of the machinery</td>
<td>up to 150 kg</td>
<td>up to 1000 kg</td>
</tr>
<tr>
<td><strong>Quantities, rough values</strong></td>
<td>single parts, small batch series</td>
<td>small batch series up to large-batch production</td>
<td>medium batch series up to large-batch production</td>
<td>single parts, small batch up to medium batch series</td>
</tr>
<tr>
<td><strong>tolerance range for 500 mm nominal size (*)</strong></td>
<td>2.5% up 5%</td>
<td>1.5% up 3%</td>
<td>1% up 2%</td>
<td>0.3% up 0.8%</td>
</tr>
<tr>
<td><strong>typical part</strong></td>
<td>pump case</td>
<td>piston rings</td>
<td>ribbed cylinder head</td>
<td>hip-joint implate</td>
</tr>
</tbody>
</table>

(*) : The specified tolerances are rough values for a nominal size of about ca. 500 mm; they depend on the grade of accuracy, the part size and the material. Material related tolerance specification see also DIN1680 and DIN 1683 up to DIN 1688.

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- **Production of consumable moulds and cores**
  - **Casting processes**
    - Casting in consumable moulds with permanent patterns
    - Survey of different processes
    - Sand casting process
    - Shell casting process
    - Casting in consumable moulds with consumable patterns
    - Casting in permanent moulds without patterns
- **Case studies**: Simulation during design and production
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- **Comparison of costs**
- **Summary**
Work flow of the sand casting process

Examples for application - Sand casting (hand moulding)

Driving wheel for a belt drive
material: GJL-300
diameter: 2850 mm

Base of a vertical boring and turning mill
material: GJL-200
diameter: 5800 mm
weight: 44 t
Example of application - Components of a ship's propulsion

- **process:** sand casting
- **material:** CuAl9Ni7, CuAl10Fe5Ni5
- **weight:** 1 propeller blade ca. 1300 kg, hub ca. 3000 kg

source: Zollern

Casting in sand at a semi-automatic moulding facility

source: konstruieren+gessen 2/2000
Example of application: Pump case - sand casting

Pump case made of low alloy GJL-300
single weights: 362 resp. 144 kg

source: konstruieren+giessen 2/2000

Example of application: Power transmission - sand casting

Truck wheel hub
(light weight design)
nodular cast iron
GJS-400-15
weight: 17.6 kg

Differential casting
nodular cast iron

Crankshaft
nodular cast iron
GJS-600-3
weight: 13.4 kg

source: Georg Fischer, Mettmann
Example of application: Aluminium sand casting

- **Suction inlet**
  - Al - sand casting, G-AlSiCu3
  - Weight: 16.8 kg

- **Oil pan**
  - Al - sand casting / G-AlSiMg(wa)
  - Weight: 4.5 kg

- **Clutch housing**
  - Al - sand casting / G-AlSi9Cu3
  - Weight: 44.6 kg

Source: Georg Fischer, Friedrichshafen

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Work flow of the shell casting process

1: 250° hot pattern board
2: pre-baked shell mould
3: tilting the excessive mould material
4: curing the mould
5: lift-off fixture
6: joining press
7: casting of the mould on a casting bed

Example of application: Shell casting process

metal pattern board
casting mould and cast parts

source: UG Metal, Dk
Structure of the lecture Casting

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**Casting processes**
- Casting in consumable moulds with permanent pattern
- Casting in consumable moulds with consumable patterns
  - Survey of different processes
  - Investment casting
  - Full mould casting
- Casting in permanent moulds without patterns

**Case studies:** Simulation during design and production
- Case study: Rapid-Prototyping used at production of casting patterns

**Comparison of costs**

**Summary**

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Survey: Casting in consumable moulds with consumable patterns

<table>
<thead>
<tr>
<th>Process</th>
<th>Investment casting</th>
<th>Full mould casting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Possible materials</strong></td>
<td>all metals</td>
<td>all metals</td>
</tr>
<tr>
<td><strong>Weights (mass)</strong></td>
<td>1 g up to several kg (in special cases up to 100 kg)</td>
<td>no restriction (available transportation equipment), specially suitable for heavy transports</td>
</tr>
<tr>
<td><strong>Quantities, rough values</strong></td>
<td>small batch series up to large-batch production</td>
<td>single parts, small batch series (at suitable parts series production)</td>
</tr>
<tr>
<td><strong>tolerance range for 500 mm nominal size (</strong>)**</td>
<td>0.3% up to 0.7%</td>
<td>3% up to 5%</td>
</tr>
<tr>
<td><strong>typical part:</strong></td>
<td>turbine wheels</td>
<td>machine base</td>
</tr>
</tbody>
</table>

(***): The specified tolerances are rough values for a nominal size of about ca. 500 mm; they depend on the grade of accuracy, the part size and the material. Material related tolerance specification see also DIN1688 and DIN 1683 up to DIN 1688.

**source:** ZGV
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  - Casting in consumable moulds with consumable patterns
    - Survey of different processes
    - Investment casting
    - Full mould casting
  - Casting in permanent moulds without patterns

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Summary

Work flow of the investment casting process - part 1

- production of a wax pattern
- joining single wax pattern to „clusters”
- each wax cluster is robotically dipped into a ceramic slurry, drained, and then coated with fused silica sand
- injection dies with wax pattern
- ceramic dipping baths ensure a firm ceramic cover

source: ZGV, Feinguss Blank
Work flow of the investment casting process – part 2

1. Dewaxing
2. Baking of the ceramic shell mould
3. Pouring the liquid material in the ceramic shell
4. Removing the ceramic shell

- About 1400°C in the furnace
- Filling the preheated shell mould with liquid metal at ~1200°C
- Separating the castings is always done manually

Source: ZGV, Feinguss Blank

Removing the wax pattern from the injection moulding die

Source: Zollern
Design guideline - curved channels

Curved channels are particularly cost-effective, when they can be produced with core slides inside the workpiece.

In all other cases, water-soluble or ceramic cores have to be used.

Source: Zollern

Design guideline - reduction of ingates

The number of ingates can be reduced through placing cut-outs ⇒ reduction the grad of bulkiness the effort during casting

Possible ingate  favourable ingate

Saved ingate
Two-piece wax pattern for a pump case part

Composite patterns
- joining splitted patterns using fitting-marks
- undercut-contures possible
- at symmetrical patterns which consist of two parts, only one injection moulding die is necessary

Examples for wax patterns and respective cast parts

Wax injection moulding with cermaic cores | Wax patterns and cast parts

**filter eye**
material: G - X5 Cr Ni Mo Nb 18/10

**turbine wheels**
material: G - X5 Cr Ni Mo Nb 18/10

source: Zollern
Examples for investment casting parts: Aerospace applicat.

**Steering knuckle made**
made of 1.7744 (tempered steel); 6.0 - 8.0 kg

**Turbine wheels and nozzle rings**
made of Ni-base-alloys, weight: 1.3 - 3.0 kg

**Load carrier and holder for landing flap**
made of 1.7744, weight: 3.2 and 4.0 kg

**Different structural parts for aircraft turbine engine hydraulics**
made of precipitation-hardened, corrosion-resistant steel,
weight: 0.4 - 2.3 kg

source: Thyssen

Examples for investment casting parts: High-tech components

Steel investment cast parts made of G-X6CrNi 18.9.
Parts of a component insertion machine, which are exposed with accelrating power up to 3.5 g.

**Top holder:**
dimensions: 165 x 150 x 190 mm
material: 1.4308 (G-X6CrNi 18.9)
weight: 1340g

**Portal S 50**
dimensions: 600 x 305 x 95 mm
material: 1.4308 (G-X6CrNi 18.9)
weight: 6800g

source: Thyssen, konstruieren+giessen 25 (2000) Nr.4
Examples for investment casting parts: Engineering industry

Head piece of a pneumatic nailing machine
material: GS-15 CrNi6 (1.5919)
dimensions: 80x80x128 mm
weight: 800 g

Lever for a packing machine
material: GS-42 CrMo4 (1.7225)
dimensions: 215x115x107 mm
weight: 6.3 kg

Casing for a hydraulic system
material: GS-45 CrMo4 (1.0443)
dimensions: 215x115x107 mm
weight: 1.9 kg

Spiral pump casing – food processing industry
material: G-X 5 CrNiMoNb 18 10 (1.4581)
dimensions: 245 x 265 x 30 mm
weight: ca. 7 kg

Valve chamber
material: GS-38 (1.0416)
weights of pieces: up to 30 kg

source: ZGV
Examples for investment casting parts

Compressor impeller
material: G-X 5 CrNiMo 165 (1.4405)
weight: 16 kg

Casing, impeller and cap for a pump used in the food processing industry
material: G-X 5 CrNiMoNb 1810 (1.4581)
diameter of casing: 220 mm
weights of pieces: up to 4.5 kg

source: Thyssen

Examples for investment casting parts: Medical engineering

Hip-joint implants
material: G-TiAl6V4

Implants for hip and knee joints
material: G-TiAl6V4

source: Tital
Structure of the lecture Casting

Introduction: Variety of applications
Basics of casting
Production sequence at casting
Production of casting patterns
Production of consumable moulds and cores

Casting processes
- Casting in consumable moulds with permanent pattern
- Casting in consumable moulds with consumable patterns
  - Survey of different processes
  - Investment casting
  - Full mould casting
- Casting in permanent moulds without patterns

Case studies: Simulation during design and production
Case study: Rapid-Prototyping used at production of casting patterns
Comparison of costs

Summary

Work flow of full-mould casting

source: ZGV

consumable foamed plastic pattern

pattern embedded in a one-piece moulding box

without core!

without burrs!
Foamed plastic pattern for a base of a machine tool

Pattern made of polystyrene foam for a base of a machine tool (casting company)
dimensions: 4800 x 2300 x 1650 mm
weight of cast part: 9,5 t
material: EN-GJL-300 (GG-30, Ferrocast)

source: konstruieren+giessen 3/99

Structure of the lecture Casting

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    - Casting in consumable moulds with consumable patterns
    - Casting in permanent moulds without patterns
      - Survey of different processes
      - Diecasting
      - Permanent mould casting
      - Centrifugal casting
      - Continuous casting
  Case studies: Simulation during design and production
  Case study: Rapid-Prototyping used at production of casting patterns
Comparison of costs
Summary
Survey: Casting in permanent moulds without patterns

<table>
<thead>
<tr>
<th>Process</th>
<th>Diecasting</th>
<th>Permanent mould casting</th>
<th>Centrifugal casting</th>
<th>Continuous casting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Possible materials</strong></td>
<td>diecasting alloys on Al-, Mg-, Zn-, Cu-, Sn- or Pb-base (ferrous materials in development)</td>
<td>light alloys, special copper based alloy, high-purity zink, lamellar and nodular graphite cast iron</td>
<td>lamellar and nodular graphite cast iron, cast steel, light alloys, copper based alloys</td>
<td>lamellar and nodular graphite, cast iron, Cu-alloys</td>
</tr>
<tr>
<td><strong>Weights (mass) rough values</strong></td>
<td>Al-alloy.: up to 50 kg</td>
<td>up to 100 kg (in special cases also higher)</td>
<td>up to 5000 kg</td>
<td>depends on cross section, up to several tons</td>
</tr>
<tr>
<td><strong>Quantities, rough values</strong></td>
<td>Zn-alloy.: up to 20 kg Mg-alloy.: up to 15 kg Cu-alloy.: up to 5 kg (restricted by the size of the diecasting machine)</td>
<td>series production, service life of dies: Al: 80,000 castings Cu: 10,000 castings</td>
<td>series production, service life of dies: Cu: 10,000 castings</td>
<td>length of cast billet depends on machine</td>
</tr>
<tr>
<td><strong>tolerance range for 500 mm nominal size (*)</strong></td>
<td>0.1% up to 0.4%</td>
<td>0.3% up to 0.6%</td>
<td>1%</td>
<td>0.8%</td>
</tr>
<tr>
<td><strong>typical part</strong></td>
<td>oil pan, gera case</td>
<td>piston</td>
<td>tubes</td>
<td>profiled bars</td>
</tr>
</tbody>
</table>

(*) The specified tolerances are rough values for a nominal size of about ca. 500 mm; they depend on the grade of accuracy, the part size and the material. Material related tolerance specification see also DIN 1680 and DIN 1683 up to DIN 1688.

Source: ZGV

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Case studies: Simulation during design and production
Case study: Rapid-Prototyping used at production of casting patterns
Comparison of costs

Summary
Principle of a hot-chamber diecasting machine

- Closing cylinder
- Toggle mechanism (interlock)
- Core plate (moveable)
- Cavity plate (fixed)
- Clamping frame
- Diecasting mould
- Injection cylinder
- Press ram
- Filling chamber
- Melting crucible
- Extrusion die (nozzle)

Hydro-mechanical cold-chamber diecasting machine

- Source: ZGV

Legend:
- a: closing cylinder
- b: round nut
- c: head plate
- d: toggle lever
- e: ejector cylinder
- f: toggle link carrier
- g: core plate (moveable)
- h: pillar
- i: ejector die
- j: cover die
- l: cavity plate (fixed)
- m: pressure chamber
- n: injection shot cylinder

Source: ZGV
### Operation cycle at cold-chamber diecasting process

I. 

II. 

III. 

IV. 

source: Schimpke, Schroop

---

### Arrangement of core pullers at diecasting mould

- core puller 1
- core puller 2
- core puller 3
- cover die
- ejector die
- filling port
- distributor core

source: Schimpke, Schroop
Classification of the process: cold-chamber diecasting
Range of VACURAL parts: high quality production of thin walled Al- and Mg-parts of high strength

Examples of application
thin walled parts of the car body as alternative to metal forming technologies

Example of application - diecasting: Truck oil pan and die

source: Härer-Werkzeugbau
Example of application - diecasting: Gear case and converter

**Gear case**
- material: aluminium diecasting AlSi9Cu3
- weight: 5.4 kg

**Torque converter housing HP500, ZF**
- material: aluminium diecasting AlSi9Cu3
- dimensions: 542 x 553 x 553 mm
- wall thickness: 3.5 - 25 mm
- weight: 41.0 kg

*source: (1) Georg Fischer, Herzogenburg; (2) Honsel*

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Structure of the lecture Casting

**Introduction:** Variety of applications

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**Production sequence at casting**

**Production of casting patterns**

**Production of consumable moulds and cores**

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  - Continuous casting

**Case studies:** Simulation during design and production

**Case study:** Rapid-Prototyping used at production of casting patterns

**Comparison of costs**

**Summary**
Work flow at permanent mould casting

- melting
- casting
- heat treatment
- machining
- quality control

Casting in permanent mould!

mould material:
- hot forming tool steel
- heat resisting special alloys

source: Gontermann-Peipers

Principle of a two-piece casting die with core

- core puller
- runner gate
- feeder
- cast part
- 1st mould half
- 2nd mould half
Principle of low-pressure permanent mould casting

Examples of application - Permanent mould casting

Source: Gontermann-Peipers
Example of application - Aluminium permanent mould casting

**Gear case**
aluminium permanent mould casting
material: G-AlSi10Mg(wa)
weight: 17.0 kg

**Slide part of a chassis / left and right**
aluminium permanent mould casting
material: GK-AlSi7Mg(wa)
weight: 2.1 kg / 2.1 kg

source: Georg Fischer, Mettmann

---

Comparison of permanent mould casting and casting in sand

<table>
<thead>
<tr>
<th></th>
<th>permanent mould casting</th>
<th>casting in sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>expenditure of work and material; transport effort and energy expense per workpiece</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>risk to produce scrap</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>thin walls of cast parts possible</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>fine grain</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>automatable</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>
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Case studies: Simulation during design and production
Case study: Rapid-Prototyping used at production of casting patterns
Comparison of costs
Summary

Differentiating criteria at centrifugal casting

<table>
<thead>
<tr>
<th>rotation axis</th>
<th>mould</th>
<th>cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>horizontal</td>
<td>metal</td>
<td>cooled</td>
</tr>
<tr>
<td>vertical</td>
<td>sand lining</td>
<td>not cooled</td>
</tr>
</tbody>
</table>

Examples:

a, c: metal mould with horizontal rotation axis, without cooling
b: metal mould with core and vertical rotation axis, without cooling

c) source: Spur
Production of pressure pipes with centrifugal casting

- stationary rotational cylinder
- sand lining
- core for sleeve
- cam roller
- foundry ladle
- gate channel

Centrifugal- und gravitational force at centrifugal casting

Division of forces within the melt at horizontal centrifugal casting:

\[ F_{\text{ex}} = F_{\text{C}} + G \]

Position of liquid metal in the permanent mould at different rotational speeds of the centrifugal casting machine:

\[ v_3 > v_2 \]
\[ v_4 > v_3 \]

Source: Spur
Example of application: Materials at centrifugal cast part

examples for materials (acc. to Gontermann-Peipers):
- lamellar graphite cast iron acc. to EN 1561 (prior DIN 1691)
- nodular graphite cast iron acc. to EN 1563 (prior DIN 1693)
- austenitic cast iron acc. to DIN 1694
- alloyed cast iron qualities acc. to customers request

Examples of application: Centrifugal casting

source: IPO, Sophia

source: GTR
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Case studies: Simulation during design and production
Case study: Rapid-Prototyping used at production of casting patterns
Comparison of costs
Summary

Principle of vertical continuous casting

- Foundry case
- Gate pot
- Permanent mould
- Cooling water
- Water spraying
- Driving pulleys
- Cutting-off device
- Block tilter
Principle of horizontal continuous casting

Source: Gontermann-Peilpers

Structure of the lecture Casting

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Casting processes
- Case studies: simulation during design and production
  - Starting point: FE-analysis and tool design
  - Simulations
  - Critical areas at the cast part
  - Results of optimization
- Case study: Rapid-Prototyping used at production of casting patterns
Comparison of costs
Summary
Casting simulation and process optimization at Al-wheel

- new aluminium wheel is designed
- Production by using the low-pressure permanent mould casting process
- Simulation should help to reduce casting defects up front
  - optimization of casting design for improved quality
  - optimization of mould tempering for improved quality
- The residual stress in the as cast condition should be considered at the FE-analysis

source: Magma

Integrated CAE technologies support simultaneous engineering

source: Magma
Casting design: 3D CAD construction of the new Al-wheel

FE-analysis of the cast part

Stress and distortion under test load (3.500N in 630mm distance of the mounting plate). The maximum stress value is about 80MPa.
Casting design - Tool geometry

Top core

Bottom core and slide

Source: Magma

Tool and cooling channels

Cooling channel

Ingate

Cooling channel

Die sections

Source: Magma
Structure of the lecture Casting

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    - Results of optimization
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Comparison of costs
Summary

Temperatures during filling

source: Magma
Solidification sequence

source: Magma

Cooling measures

- water, 30°C
- air, 60°C
- air, 30°C
- ingate
- casting sections

All cooling channels with individual time control

source: Magma
Tool temperatures - closed die

source: Magma

Tool temperatures - before opening

High tool temperatures mean low heat reduction from the casting

source: Magma
Tool temperatures - upper core opens

Tool temperatures - before closing the die
Tool temperatures - closed tool, before next cycle

Structure of the lecture Casting

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    - Results of optimization
  - Case study: Rapid-Prototyping used at production of casting patterns
- Comparison of costs
- Summary
Critical section for feeding

- Density between 90% and 100%
- Solidification time between 10s and 80s
- Pores
- Hot spots

source: Magma

Residual stress and total deformation 1 (3)

The residual stress is in the order of magnitude of the stress caused by the test load

source: Magma
Residual stress and total deformation 2 (3)

Residual stress plus load stress...

source: Magma

Residual stress and total deformation 3 (3)

.... results in the total stress under load, that can be in the range of the yield strength.

source: Magma
Structure of the lecture Casting

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  - Results of optimization
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Comparison of costs
Summary

Output of optimization: Reduced porosity and better feeding

Density between 90% and 100%

Solidification time between 10s and 80s

- strongly reduced porosity
- better feeding through the spoke

source: Magma
Summary of the simulation case study „Al-wheel“

- The integrated casting simulation / FE-analysis of the original wheel design provided the following information:
  - casting defects due to hot spots and insufficient feeding would occur
  - the addition of residual stress and test load would lead to maximum total stress values above the yield strength
- Optimization measures have been worked out
  - tapering to support feeding
  - thicker spokes to support feeding and to reduce the maximum stress values
- The optimization measures were proofed by casting simulation and FE-analysis

source: Magma

Structure of the lecture Casting

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- Casting processes
- Case studies: simulation during design and production
- Case study: Rapid-Prototyping used at production of casting patterns
  - Starting point and result of optimization
- Comparison of costs
- Summary
Example of application: High speed supporting table (1)

- Design if possible right-angled!
- No big and abrupt change of cross section!
- Designing the cells in the same size!
- Avoid that ribs run together at one node!
- Minimum wall thickness at cast part: 20 mm!

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>1400 mm</td>
</tr>
<tr>
<td>Width</td>
<td>500 mm</td>
</tr>
<tr>
<td>Height</td>
<td>150 mm</td>
</tr>
<tr>
<td>Transverse acceleration</td>
<td>2 g</td>
</tr>
<tr>
<td>Transverse deformation</td>
<td>4 µm</td>
</tr>
<tr>
<td>Production</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Example of application: High speed supporting table (2)

Load orientated ribbing

- Deformation: -50 %
- Mass: -15 %
- Costs: -10 %

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>1400 mm</td>
</tr>
<tr>
<td>Width</td>
<td>500 mm</td>
</tr>
<tr>
<td>Height</td>
<td>150 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>140 kg</td>
</tr>
<tr>
<td>Transverse acceleration</td>
<td>2 g</td>
</tr>
<tr>
<td>Transverse deformation</td>
<td>2 µm</td>
</tr>
<tr>
<td>Material</td>
<td>EN-GJS-400-18</td>
</tr>
</tbody>
</table>
Production time of Al-precision cast parts-conventional and RP

<table>
<thead>
<tr>
<th>Step</th>
<th>Conventional</th>
<th>Rapid-Prototyping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing</td>
<td></td>
<td>CAD-Data</td>
</tr>
<tr>
<td>Tool</td>
<td></td>
<td>Rapid-Prototyping</td>
</tr>
<tr>
<td>Wax pattern</td>
<td></td>
<td>pattern</td>
</tr>
<tr>
<td>Investment casting</td>
<td>ca. 6 weeks</td>
<td>ca. 1 week</td>
</tr>
<tr>
<td>Cast part</td>
<td></td>
<td>cast part</td>
</tr>
</tbody>
</table>

Σ = 12 weeks  Σ = 4 weeks

source: Tital

Example of application: Pattern for a gear case

**Quickcast™ - Model**
Gear Case VW / Wolfsburg

**Cast part**
- material: GF-AI/7Mg0.6
- weight: 18 kg

source: Tital
Structure of the lecture Casting

- Introduction: Variety of applications
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- Comparison of costs
- Summary

Comparison of manufacturing costs for a gear case

The graph compares different manufacturing methods, including all extra charges, for a gear case. The methods compared are:
- Diecasting
- Investment casting
- Conventional cutting processes
- Casting in sand

The chart shows the manufacturing cost index of different manufacturing methods. The x-axis represents the number of produced parts, while the y-axis shows the percentage manufacturing cost. The specific case study involves a pump case made of aluminium-alloy.
Investment casting contra assembling: Aerospace application

1- prior ⇒ 2 - today

<table>
<thead>
<tr>
<th>manufacturing</th>
<th>assembling of 9 milled parts</th>
<th>investment casting</th>
</tr>
</thead>
<tbody>
<tr>
<td>material</td>
<td>titanium</td>
<td>titanium</td>
</tr>
<tr>
<td>mass</td>
<td>4500 g</td>
<td>4400 g</td>
</tr>
<tr>
<td>costs for fixtures resp. tools</td>
<td>100 %</td>
<td>64.6 %</td>
</tr>
<tr>
<td>costs for material</td>
<td>100 %</td>
<td>96.5 %</td>
</tr>
<tr>
<td>costs for machining resp. assembling</td>
<td>100 %</td>
<td>3.9 %</td>
</tr>
<tr>
<td>manufacturing costs</td>
<td>100 %</td>
<td>50.5 %</td>
</tr>
</tbody>
</table>

source: Tital

Structure of the lecture Casting

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Comparison of costs
Summary
Catalogue of questions to summarize the lecture „CASTING“

- Explain the change of the crystal lattice during cooling down the liquefied material at the example of pure iron!
- Outline and explain the globulitical, fringe crystal and monocrystalline solidification at turbine blades!
- Coarse grain contra fine grain!
- Nominate and explain different casting properties (5)!
  What is meant with „shrinkage cavitation“ and how does that casting damage arise?
- How are the moulding and casting processes defined?
- Nominate and explain different methods of core production!
- Into which main groups (3) are the casting processes classified?
- Explain the principal work flow of the casting processes which belong to the three main groups!
- Nominate and explain the essential parts of a casting simulation!
- Explain the proceeding of the rapid-prototyping process for production of casting patterns!

Structure of the exercise Casting

Introduction

Requirement oriented design of cast parts
  - Casting faults
  - Shape and casting oriented design
  - Load oriented design
  - Machining oriented design

Film: Presentation and definition of casting processes

Exercises
  - Requirement oriented design of cast parts
  - Selecting a casting process