The Zollern factories

The ZOLLERN GmbH & Co. KG is a company with worldwide operations, employing over 2400 employees in the business fields of transmission technology (automation, gears and winches, friction bearing technology), engineering elements, foundry technology and steel profiles.
In the field of castings technology, the ZOLLERN Company is not only one of the foremost names in Europe but also a highly respected exporter to some of the most important industrial notions in the world. After all, we have been making castings for around one hundred years. ZOLLERN helped to shape every stage in the development of the technology, from the production of simple cast iron at the end of the 19th century to the most modern technologies in use today.

Our origins, however, go a lot further back. Prince Meinrad II of Hohenzollern founded the smelting plant which bore his name and consisting of a blast furnace and hammer mill as long ago as 1708. During the 280 years since then, the original iron works at Laucherthal (near Sigmaringen) has developed into a Company employing 2000 people and operating on an international scale. Today, ZOLLERN concentrates primarily on producing castings by a variety of methods (investment, sand, shell, mould, Shaw, continuous and centrifugal); it also has forging and drawing facilities at its disposal.

At the same time, ZOLLERN is also well known as a manufacturer and supplier of drive systems, handling equipment and machine components, with the result that the expertise obtained from all the industrial sectors which the Company supplies is utilised synergically to the advantage of customers for ZOLLERN castings.
Investment casting is taken to mean casting into single-piece ceramic shell moulds, eliminating the mould (pattern) parting line and the imprecision and flash associated with it. The characteristic feature of Investment casting is that the pattern is melted away and thus lost. The process is described by the following detail production steps.

Investment castings is a precision casting method which is growing steadily in international significance for reason of economy. The method is being used to produce larger and larger castings. Investment castings is also employed on an increasing scale for so-called super alloys which require ever more complex smelting processes. Due to the economic benefits it offers, increasing weight is being attached to investment casting in comparative value analyses. Its scope for optimum shaping is unmatched by any other casting method. Investment castings-oriented design frequently offers an answer to technical problems which would be either impossible or far more expensive to implement using any other method.

Material selection
All castable materials can be processed using this method. Investment casting is particularly suitable for use with materials unsuited to machining.

Surface quality
The casting are produced without any trace of flash, and with an excellent surface finish. In many cases—expect for producing the required seat dimensions – there is no need for a follow-on machining process.

Piece weights
Generally speaking, the investment casting technique is used for small piece weights of between 1 g and 10 kg. Larger workpieces up to 150 kg are also possible.

Summary
The investment casting technique is characterized by
• Almost unlimited scope for the shaping of castings
• Hardly any restrictions in terms of materials
• A high degree of dimensional accuracy due to elimination of the mould parting line usually responsible for casting imprecision
• Facility for complex shaped inner contours due to the use of ceramic cores
• Low material allowance on surfaces to be machined
• A high standard of surface quality
1. For every casting, a wax pattern has to be produced. Patterns are manufactured using an injection moulding machine in metal moulds made of soft metal alloy, aluminium or using wax.

2. The patterns are glued either individually (in the case of large workpieces) or in groups forming ‘clusters’ to a gating system (sprue, gates, feeder) which is also manufactured using wax.

3. up to 5. By repeated immersion of the patterns in a ceramic slurry followed by packing in sand, after drying and where necessary chemical hardening, the patterns are surrounded by a refractory ceramic cell between 6 and 10 mm thick.

6 and 7. After drying and curing of the mould material, the wax patterns are melted and the moulds fired at temperatures up to 1100° C.

8. Casting is carried out by pouring into the moulds while hot. As even the finest details of the mould are completely filled, a compact casting result is achieved.

9. up to 12. After cooling and knocking out of the filled moulds, the casting are separated, machined and subjected to a final inspection.
TOLERANCES AND SURFACES

Using the investment casting method, economical dimensioning means ensuring that no tolerance is selected closer than necessary for the intended purpose. Dimensional tolerances, surface and machining allowances are generally laid down by the Technical Memorandum of the VDG (German Association of Foundry Specialists), P 690. The accuracy level D 1 is generally taken to be the free size tolerance for casting which demonstrate an average degree of complexity. Accuracy level D2 applies to casting dimensions within tolerated limits. Accuracy level D3 corresponds to the range of variation between different production batches and applies only to dimensions for largescale series which have been agreed with the producer. In order to achieve D3 tolerances, it is often necessary to correct or 'redress' the tool by means of trail gating processes. For this reason, it can be more economical to adjust the counter-part when mating for tolerance to the actual dimension of the casting.

Linearity, evenness, parallelism
Tolerances for linearity, evenness and parallelism as well as line and area shape are specified in Table 1 on the right. Small local irregularities in the surface such as shrink marks or pimples are not taken into account.

Angular tolerances
As the permissible misalignment can occur to either side, no ± signs are specified in the VDG Memorandum. The respective tolerance value of the table in mm per 100 mm applies to the shorter arm of the angle at the workpiece and must be rounded up to the next full tenth.

Machining allowances
For closer tolerances than those specified above, machining allowances are necessary. Table 2 provides guideline values for this. These must be added to or deducted from the respective limiting dimensions. The machining allowance in each individual case depends on the material used and the type of machining process, and therefore must be agreed separately with the producer.

Table 1: Tolerances for linearity, flatness, parallelism and line area shape*

<table>
<thead>
<tr>
<th>Accuracy level</th>
<th>Length of tolerated element</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>up to 25 mm</td>
</tr>
<tr>
<td>Permissible dimensional variation</td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>0.15 mm</td>
</tr>
<tr>
<td>D2</td>
<td>0.10 mm</td>
</tr>
<tr>
<td>D3</td>
<td>0.10 mm</td>
</tr>
</tbody>
</table>

*Without/with reverence dimensions tolerated in accordance with immersion casting principles
### Table 3: Surface qualities to DIN ISO 1302

<table>
<thead>
<tr>
<th>CLA (µinch)</th>
<th>$R_a$ [µm]</th>
<th>$R_z$ [µm]</th>
<th>$R_t$ [µm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>N 1</td>
<td>1</td>
<td>0.025</td>
<td>0.22–0.30</td>
</tr>
<tr>
<td>N 2</td>
<td>2</td>
<td>0.050</td>
<td>0.15–0.60</td>
</tr>
<tr>
<td>N 3</td>
<td>4</td>
<td>0.10</td>
<td>0.8–1.1</td>
</tr>
<tr>
<td>N 4</td>
<td>8</td>
<td>0.20</td>
<td>1.0–1.8</td>
</tr>
<tr>
<td>N 5</td>
<td>16</td>
<td>0.40</td>
<td>1.6–2.8</td>
</tr>
<tr>
<td>N 6</td>
<td>32</td>
<td>0.80</td>
<td>3.0–4.8</td>
</tr>
<tr>
<td>N 7</td>
<td>63</td>
<td>1.60</td>
<td>5.9–8.0</td>
</tr>
<tr>
<td>N 8</td>
<td>125</td>
<td>3.20</td>
<td>12–16</td>
</tr>
<tr>
<td>N 9</td>
<td>250</td>
<td>6.30</td>
<td>23–32</td>
</tr>
<tr>
<td>N 10</td>
<td>500</td>
<td>12.50</td>
<td>46–57</td>
</tr>
<tr>
<td>N 11</td>
<td>1000</td>
<td>25.00</td>
<td>90–110</td>
</tr>
<tr>
<td>N 12</td>
<td>2000</td>
<td>50.00</td>
<td>180–220</td>
</tr>
</tbody>
</table>

1) $R_a$, $R_z$ and $R_t$ are approximated values.
2) Formation of relationship between $R_a$, $R_z$ and $R_t$ is not permissible.

### Sure characteristics

The surfaces are free of scoring and comply with two surface categories/classes N7 to N9 according to table 3. Unless otherwise agreed, N9 in a sand-blasted surface finish is supplied as standard (see VDG Memorandum point 5).

### Table 2: Machining allowances depending on the type of machining (all values in mm)

<table>
<thead>
<tr>
<th>Greatest nominal dimension over</th>
<th>Allowance per surface up to</th>
<th>coarse</th>
<th>fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>50</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>50</td>
<td>80</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>120</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>220</td>
<td>1.5</td>
<td>0.5</td>
</tr>
<tr>
<td>220</td>
<td>500</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>500</td>
<td>-</td>
<td>&gt; 2.0</td>
<td>&gt; 1.5</td>
</tr>
</tbody>
</table>
INVESTMENT CASTINGS: TERMS OF DELIVERY

Part 1: General conditions

1. Applications
VDG Specification P 695 lays down the general technical terms of delivery for investment castings made by the lost wax method from standard and non-standard casting materials or metals. Additional, specific requirements relating to certain materials are laid down in separate standards.

The purchaser specifies his requirements for the casting in accordance with its intended purpose. Appendix A of the specification contains a check list providing negotiators with rapid information about various points which can be agreed when an order is placed. These refer to corresponding sub-sections and extracts from the VDG specification.

We expressly recommend that only materials be chosen which qualify as casting materials in official standards.

Part 2: Quality grades

1. General
The present specification lays down various grades of external and internal quality for the condition of materials on delivery. The grades are subdivided in accordance with the requirements which the results of non-destructive tests must meet.

2. Quality grades
2.1 Allocation of quality grades
The allocation of external quality grades is determined in accordance with tests based on the magnetic leakage-flux method or dye method.

The allocation of internal quality grades is determined by a radiographic test and/or X-ray examination.

Extract from the guideline drawn up by the Investment Castings Committee of the VDG (Association of German Foundrymen).
1. Definition and scope

1.1 Investment casting is a process by which a high surface quality can be manufactured through the formation of dimensionally accurate casting. The patterns produced by injection moulding are heat disposable and are melted out after manufacture of the ceramic moulds. The ceramic moulds are destroyed after casting. For this reason, both the pattern and the moulds are designated ‘lost’ using this method. Casting usually takes place into hot moulds.

1.2 Metals and iron, aluminium, nickel, cobalt, titanium, copper and magnesium-based alloys can be used for investment casting. Depending on the type of alloy, casting is performed exposed to the air, under inert gas in a vacuum.

1.3 This technical memorandum does not apply precious metals cast using the dewaxing method, to products of the jewellery industry, dental laboratories or to art casting.

2. Purpose

2.1 This technical memorandum defines dimensional tolerances, specifies machining allowances and surface roughness corresponding to the start of the art in the field of investment casting. It serves as a basis for optimum economic cooperation between investment casting suppliers and buyers.

2.2 The specifications mentioned here refer to sandblasted preserved or pickled surfaces in their delivered condition. Exception must be agreed where work processes are involved which alter the dimensional tolerances.

2.3 Unless otherwise agreed, initial samples are supplied for first-time orders. These are used to permit concrete mutual agreement between supplier and purchaser. Initial samples must be appraised by the buyer, followed by a written release to the foundry for series production. Deviation acknowledged by the release or with positive appraisal of the initial samples are binding for the production process and must be entered into the (casting) drawing.
3. Dimensional accuracy

3.1 Contraction and shrinkage
During the solidification and cooling of cast metals, a contraction of the volume naturally occurs as a result of shrinkage. Other factors influencing the production of instrument castings can result from the shrinkage of the lost pattern and the expansion of moulds during heating. The sum of these influencing factors is taken into consideration in the shrinkage allowance during the manufacture of injection moulds. The shrinkage allowance is based on experience values, depending on the contour of the casting, the ceramic shell and the casting materials, as well as the casting techniques used in the individual foundries.

3.2 Reference planes and reference points
Drawing used in the manufacture of casting must be gauged systematically using reference or locating points in order to ensure that dimensional checks and subsequent machining are in agreement. Reference points must be determined right from the early design stage and coordinated between the zero position of the reference planes is precisely defined by means of the reference point dimensions. All reference points must be arranged in such a way that they are not removed or altered during the subsequent machining process. Reference points should be positioned on the outside surfaces of the investment casting. They may take the form of raised or reference points are beneficial when dealing with castings with restricted shape and position tolerances. When determining the reference points, attention should be paid to ensuring that they do not fall in the area of a sprue. In case of complex shaping, it is possible in this way to position the casting precisely by (pre-) machining the locating points.

3.3 Overdefinition
According to DIN 406, overdefinition must be avoided. Wall thicknesses must always be specified.

3.4 Mould and draught angles
Mould and draught angles are not necessary as a general rule. Exceptions to this for reason of mouldmaking or casting necessity must be agreed between the investment casting supplier and the buyer.
4. Dimensional tolerances

4.1 Linear dimensional tolerances

Achievable dimensional tolerances on investment casting are dependent on the following factors:

- Casting material
- Dimensions and shape of the casting
- Validity of the accuracy grade

4.1.1 Casting material

In production, the varying characteristics of the materials affect the spread of the tolerance fields. For this reason, different rows of tolerance apply in table 1 to the different material groupings:

<table>
<thead>
<tr>
<th>Material group D</th>
<th>Degree of accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron, nickel, cobalt and copper-based alloys</td>
<td>D1 to D3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material group A</th>
<th>Degree of accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium and magnesium-based alloys</td>
<td>A1 to A3</td>
</tr>
</tbody>
</table>

4.1.2. Dimensions and shape of the casting

The achievable accuracy level of the rated dimensions of an investment casting depends on the greatest dimension and the shape of the casting. If the rated dimension (GTA) exceeds the rated dimension range indicated for a certain accuracy level, the overall tolerance of the casting must be tolerated at the accuracy level (greatest tolerance field). Deviation outside the accuracy level must be agreed between the supplier and the buyer.

4.1.3 Validity of the accuracy level

In each of the material grouping D and A, there are three accuracy levels specified.

- Accuracy level 1 applies for all untolered dimensions.
- Accuracy level 2 applies for all tolerated dimensions.
- Accuracy level 3 can only be adhered to for individual dimensions and must be agreed with supplier, as for other additional production steps elaborate tool corrections are also necessary.

4.1.4 Location of the tolerance zone

The location of the tolerance zone relative to the nominal size can be freely selected. It is advisable to lay the tolerance zone evenly about the nominal size. In the case of surfaces which are to be machined, the sum / difference of the tolerance zone and machining allowance must be taken into account (see point 6).

---

Table 1: Linear tolerances (dimensions in mm)

<table>
<thead>
<tr>
<th>Range of nominal size</th>
<th>D1 Zone</th>
<th>D1 GTA</th>
<th>D2 Zone</th>
<th>D2 GTA</th>
<th>D3 Zone</th>
<th>D3 GTA</th>
<th>A1 Zone</th>
<th>A1 GTA</th>
<th>A2 Zone</th>
<th>A2 GTA</th>
<th>A3 Zone</th>
<th>A3 GTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 6</td>
<td>0.3</td>
<td>14</td>
<td>0.24</td>
<td>13.5</td>
<td>0.2</td>
<td>13</td>
<td>0.3</td>
<td>14</td>
<td>0.24</td>
<td>13.5</td>
<td>0.2</td>
<td>13</td>
</tr>
<tr>
<td>6 up to 10</td>
<td>0.36</td>
<td>14.5</td>
<td>0.28</td>
<td>13.6</td>
<td>0.22</td>
<td>13.5</td>
<td>0.36</td>
<td>14.5</td>
<td>0.28</td>
<td>13.6</td>
<td>0.22</td>
<td>13.5</td>
</tr>
<tr>
<td>10 up to 18</td>
<td>0.44</td>
<td>14.5</td>
<td>0.34</td>
<td>14.5</td>
<td>0.28</td>
<td>13.5</td>
<td>0.44</td>
<td>14.5</td>
<td>0.34</td>
<td>13.5</td>
<td>0.28</td>
<td>13.5</td>
</tr>
<tr>
<td>18 up to 30</td>
<td>0.52</td>
<td>14</td>
<td>0.4</td>
<td>14.5</td>
<td>0.34</td>
<td>13.5</td>
<td>0.52</td>
<td>14.5</td>
<td>0.4</td>
<td>14.5</td>
<td>0.34</td>
<td>13.5</td>
</tr>
<tr>
<td>30 up to 50</td>
<td>0.8</td>
<td>14</td>
<td>0.62</td>
<td>14.5</td>
<td>0.5</td>
<td>13.5</td>
<td>0.8</td>
<td>14</td>
<td>0.62</td>
<td>14.5</td>
<td>0.5</td>
<td>13.5</td>
</tr>
<tr>
<td>50 up to 80</td>
<td>0.9</td>
<td>14.5</td>
<td>0.74</td>
<td>14.5</td>
<td>0.6</td>
<td>13.5</td>
<td>0.9</td>
<td>14.5</td>
<td>0.74</td>
<td>14.5</td>
<td>0.6</td>
<td>13.5</td>
</tr>
<tr>
<td>80 up to 120</td>
<td>1.1</td>
<td>15</td>
<td>0.88</td>
<td>15.5</td>
<td>0.7</td>
<td>14.5</td>
<td>1.1</td>
<td>15</td>
<td>0.88</td>
<td>15.5</td>
<td>0.7</td>
<td>14.5</td>
</tr>
<tr>
<td>120 up to 180</td>
<td>1.6</td>
<td>15</td>
<td>1.3</td>
<td>15.5</td>
<td>1.0</td>
<td>14.5</td>
<td>1.6</td>
<td>15</td>
<td>1.3</td>
<td>15.5</td>
<td>1.0</td>
<td>14.5</td>
</tr>
<tr>
<td>180 up to 250</td>
<td>2.4</td>
<td>15.5</td>
<td>1.9</td>
<td>15.5</td>
<td>1.5</td>
<td>14.5</td>
<td>1.9</td>
<td>15.5</td>
<td>1.5</td>
<td>14.5</td>
<td>1.5</td>
<td>14.5</td>
</tr>
<tr>
<td>250 up to 315</td>
<td>2.6</td>
<td>16</td>
<td>2.2</td>
<td>15.5</td>
<td>2.8</td>
<td>15.5</td>
<td>2.6</td>
<td>2.2</td>
<td>15.5</td>
<td>2.8</td>
<td>1.7</td>
<td>14.5</td>
</tr>
<tr>
<td>315 up to 400</td>
<td>3.6</td>
<td>16</td>
<td>2.8</td>
<td>15.5</td>
<td>2.8</td>
<td>15.5</td>
<td>3.6</td>
<td>2.8</td>
<td>15.5</td>
<td>2.8</td>
<td>1.7</td>
<td>14.5</td>
</tr>
<tr>
<td>400 up to 500</td>
<td>4.0</td>
<td>16.5</td>
<td>3.2</td>
<td>15.5</td>
<td>2.8</td>
<td>15.5</td>
<td>4.0</td>
<td>3.2</td>
<td>2.8</td>
<td>15.5</td>
<td>2.8</td>
<td>1.7</td>
</tr>
<tr>
<td>500 up to 630</td>
<td>5.4</td>
<td>16.5</td>
<td>4.4</td>
<td>15.5</td>
<td>4.4</td>
<td>15.5</td>
<td>5.4</td>
<td>4.4</td>
<td>4.4</td>
<td>15.5</td>
<td>4.4</td>
<td>1.7</td>
</tr>
<tr>
<td>630 up to 800</td>
<td>6.2</td>
<td>16.5</td>
<td>5.0</td>
<td>15.5</td>
<td>5.0</td>
<td>15.5</td>
<td>6.2</td>
<td>5.0</td>
<td>5.0</td>
<td>15.5</td>
<td>5.0</td>
<td>1.7</td>
</tr>
<tr>
<td>800 up to 1000</td>
<td>7.2</td>
<td>16.5</td>
<td>5.6</td>
<td>15.5</td>
<td>5.6</td>
<td>15.5</td>
<td>7.2</td>
<td>5.6</td>
<td>5.6</td>
<td>15.5</td>
<td>5.6</td>
<td>1.7</td>
</tr>
<tr>
<td>1000 up to 1250</td>
<td>6.6</td>
<td>16.5</td>
<td>6.6</td>
<td>15.5</td>
<td>6.6</td>
<td>15.5</td>
<td>6.6</td>
<td>6.6</td>
<td>6.6</td>
<td>15.5</td>
<td>6.6</td>
<td>1.7</td>
</tr>
</tbody>
</table>

The general casting tolerance series GTA correspond to DIN 1680 Part 2
For wall thickness tolerances, see table 2.
4.2 Dimensional tolerance for wall thicknesses
The wall thickness tolerance depend on
• the size of the (ceramic) walls of the mould
• their uninterrupted surface area
• their possible thermal distortion
• the metalostatic pressure of the molten metal.

The wall thickness tolerance are, for this reason, not dependent on the level of accuracy. They are restricted (or reduced) by thicker edge sections, break-throughs (openings, holes), webs to be included in the casting, ribs and similar, which serve to ‘relieve’ the wall thickness. The tolerance range in question in each case is indicated in Table 2.

### Table 2: Wall thickness tolerances

<table>
<thead>
<tr>
<th>Smallest lateral length of a surface (Fig. 3)</th>
<th>Material group D Fe, Ni, Co, Cu based on alloys</th>
<th>Material group A Al and Mg based on alloys</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>mm</td>
<td>mm</td>
</tr>
<tr>
<td>&lt; 50</td>
<td>± 0.25</td>
<td>± 0.25</td>
</tr>
<tr>
<td>50 up to 100</td>
<td>± 0.30</td>
<td>± 0.30</td>
</tr>
<tr>
<td>100 up to 180</td>
<td>± 0.40</td>
<td>± 0.40</td>
</tr>
<tr>
<td>180 up to 315</td>
<td>± 0.50</td>
<td>± 0.50</td>
</tr>
<tr>
<td>&gt; 315</td>
<td>± 0.60</td>
<td>± 0.60</td>
</tr>
</tbody>
</table>

4.3 Shape and position tolerances
Shape and position tolerances presume the determination of reference planes and reference points as defined by DIN ISO 1101. They are dependent on the material and shape of the casting and must therefore be agreed between the supplier and buyer.

4.4 Angular tolerances for material groups D and A
Angular tolerance deviating from table 3 must be agreed with the supplier and entered in the drawing in accordance with DIN ISO 1101.

### Table 3: Angular tolerances

<table>
<thead>
<tr>
<th>Accuracy level</th>
<th>Range of nominal sizes¹</th>
<th>Permissible misalignment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>up to 30 mm</td>
<td>30 up to 100 mm</td>
</tr>
<tr>
<td></td>
<td>Angular minutes mm per 100 mm</td>
<td>Angular minutes mm per 100 mm</td>
</tr>
<tr>
<td>1</td>
<td>30¹</td>
<td>0.87</td>
</tr>
<tr>
<td>2</td>
<td>30¹</td>
<td>0.87</td>
</tr>
<tr>
<td>3</td>
<td>20¹</td>
<td>0.58</td>
</tr>
</tbody>
</table>

¹For the range of nominal sizes, the length of the short arm is authoritative.
²The angle may deviate in both directions.

4.5 Dimensional tolerances for cast-on or cast-in prefabricated parts
These must be determined in agreement with the foundry.
5. Surface properties
For cast surface, Ra (CLA) should be used in accordance with Table 4. Classes N 7, N 8 and surface treatments must be agreed separately and entered into drawing in accordance with DIN ISO 1302. Unless otherwise agreed, class N9 with sandblasted finish is assumed to be the condition on delivery.

6. Machining allowances
For sizes of fit on surface or low surface roughness factors which cannot be achieved by investment casting alone, machining allowance must take into account material-specific properties and the computational unfavorable position within the tolerance field.

Table 4: Surface roughness factors

<table>
<thead>
<tr>
<th>Surface roughness standards</th>
<th>Material group D</th>
<th>Material group A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CLA (µinch) Ra (µm)</td>
<td>CLA (µinch) Ra (µm)</td>
</tr>
<tr>
<td>N 7</td>
<td>63 1.6</td>
<td></td>
</tr>
<tr>
<td>N 8</td>
<td>125 3.2</td>
<td>125 3.2</td>
</tr>
<tr>
<td>N 9</td>
<td>250 6.3</td>
<td>250 6.3</td>
</tr>
</tbody>
</table>

7. Supplementary remarks and data

7.1 Inside radii
Radii on inside corners and inside edges (fillets) help to avoid casting faults and reduce notch stress in the casting during later use.

The minimum radius should amount to around 20% of the greatest wall thickness, but be no less than 0.5 mm. An ideal inside radius should correspond to at least the smallest wall thickness.

7.2 Outside radii and outside chamfers
Investment castings have no sharp edges with R = 0. For this reason, outside radii and outside chamfers should always be specified as maximum radii, for example R ≤ 0.5.

7.3 Holes, blind holes, channels, slots and grooves
In order to allow through holes, blind holes, channels, slots and grooves to be most beneficially included in the casting, i.e. without the need for pre-formed ceramic cores, the values specified in Tables 5 and 6 must be taken into account.

7.4 Identification of casting
If casting are to be identified, the lettering size (‘medium’ to DIN 1451) and the position of the marking on the casting must be agreed. Identifying marks may be raised or recessed, or raised within a recessed field. If there are no specifications covering this in the drawing, the manner in which identifying marks is made must be determined by the supplier.
Inside contours and undercutting

The highly developed core technology used in conjunction with investment casting permits varied and economical shaping when working with inside contours and undercutting. It is often possible to join several construction elements to form one part ‘from a single mould’ saving complex fitting work and assembly, and the extensive equipment required for these work processes. It is possible to form inside contours which impossible or extremely difficult to manufacture using other methods. For this purpose, manual insert, core slides and/or knock-out cores are used in the tool. It is also possible to assemble patterns from individual elements. Depending on the shape of the workpiece, the most economical of these possibilities can be used.

Water-soluble cores

For inside contours which are not too narrow, water-soluble cores are used. These each involve the manufacture of another tool and coated with the non-water soluble pattern material. When the core is dissolved after immersion in a water bath, the required inside contour is left.

Core slides and manual inserts

If the contour to be created so permits, core slides and/or manual inserts are provided in the tool. Where possible, the core slides are automatically ejected. However, frequently these have to be drawn manually, particularly in the case of housings with multiple undercut inside contours.

Despite the wide scope open to designers in the manufacture of investment cast components, it is advisable for considerations of economy to observe certain basic rules to keep the production input as low as possible. As a result, on the one hand the basic law of physics are obeyed during the casting process and work sequence from the tool to the finished casting, while on the other hand they indicate the scope of achievements possible using the investment casting process. In either event, a basic rule of thumb applies: The more complex the shape of a workpiece, the more difficult it is to process, the more economical it is to produce it by investment casting. Investment cast items are often cast ready for installation without further processing. Where this is not possible due to insufficient tolerances, conventional machining methods can be used. Far-thinking, sensible design simplifies the machining process, so reducing the input and improving economy.
Spatially curved surfaces
Spatially curved surfaces can be precisely reproduced true to shape using the investment casting technique. What makes this method so economical is the fact that the relatively high processing input is only necessary on one single occasion, i.e. during manufacture of the tool.

Curved channels
A feature which can be produced particularly economically are curved channels, which are shaped in such a way that they can be manufactured in the tool using core sliders. In other cases, watersoluble or ceramic cores must be used, which involve the manufacture of a special tool.

Assembled pattern
In certain cases, it is possible to assemble patterns. With the aid of fitting marks, they are precisely assembled and connected, so forming the undercut contours. This procedure is often used in cases where symmetrical patterns can be assembled from two or more identical pattern components, as then only a single (part) tool is required.

Ceramic cores
Ceramic cores are used for narrow or intricately shaped cavities in the casing involving undercuts which cannot be reached or properly filled out by the ceramic mould material during the mouldmaking process. They are inserted in the tool ready fired and, in contrast to water-soluble cores, remain in the mould until after casting.

Bulkiness
By providing recesses (=farsighted design for casting), it is possible to reduce the number of gates; this makes the tools less bulky and reduces the complexity of the casting process.
### Tooothing

The rough and finish casting of special toothing arrangements of all different types can be economically performed using the investment casting technique, in particular using heavy-duty, non-machinable materials. Applications include Gear and clutch toothing, serration, internal gears and gear-type profiles which cannot be machined using the generation grinding method, bevel and chain wheels, worm gear wheels. If the investment casting tolerances are not sufficient for the pitch and diameter, the casting must be subsequently machined, for example by grinding.

### Threads

Threads are only included in the casting if the investment casting tolerances are sufficient for the pitch and profile. This means that only the following special cases can be considered for casting:
- Interrupted threads, e.g. for bayonet catches and quick-action couplings;
- Threads which mate with materials such as rubber or plastic;
- Coarse circular or trapezoidal threads;
- Threads of alloy which are important to examine whether it might not be possible to either avoid their use by a modification of the design, or to carry out subsequent grinding.

### Cooling fins

Cooling fins should have cross-sections which taper towards the outside; this not only improves casting performance but also the heat flow.

---

**Notch effects, radii**

Not only the designer but also the caster is anxious to avoid notch effects, as sharp-edged notches (heating edges) interfere with the casting process. A casting with larger radii demonstrates a less marked stress gradient, making it more functionally reliable. The ‘rough’ surface of an investment casting demonstrates the same notch insensitivity as a finish machined surface.
Inside edges, notches
Sharp inside edges and notches are unfavorable for casting, as they act as ‘heating edges’ which can result in porosity. Instead, these points should be shaped as radii or fillet formations of at least around 20% of the wall thickness, in thin-walled components at least 0.3–0.5 mm.

Shrinkage cavities
Shrinkage cavities are a natural occurrence on the solidification of molten metal. The task of the producer is to use suitable means to make them occur not in the casting itself but in the gates, which are parted off after casting. For reason of cost, it can happen that the designer tolerates certain defined shrinkage cavities either because they occur at an uncritical location or because they will in any case be removed by a subsequent machining process. However, this must be agreed expressly with the producer. The ‘ideal casting’ is shaped in such a way that its cross-sections diminish as they progress from the gate towards more distant sections of the casting; if this ideal constellation is achieved, the solidification process can take place in the opposite direction to the gate. Castings which come closest to this ideal are those with walls of approximately equal thickness and those which offer the producer the possibility to ‘gate’ them for optimum casting. The resulting points to observe when setting about the design of an optimum investment casting are illustrated in the following.

Knurling, corrugated effects
Knurling, and corrugated, as well as fish skin effects can be included in the casting. The following pitches apply
\[ t = 0.8 \text{ mm with } \text{Fe, Ni, Co based alloys} \]
\[ t = 0.5 \text{ mm with Al and Cu based alloys}. \]

The tips always demonstrate a small natural casting radius of around 0.1 mm. All-round cross knurling demands a disproportionately high tool input and should therefore be avoided.
**Junctions**

Junctions should be configured so that no sharp internal edges or accumulations of material occur. For this reason, sloping and parallel walls should be joined to each other wherever possible at right angles.

**Mould and draught**

Mould and draught angles are only required in exceptional cases. Only where extremely long inside contours or similar exist it is necessary to provide for a slight conicity or angle.

**Gates**

Where possible, a suitable even outer surface at the thickest cross-section should be selected for the gates. This constellation will permit them to be separated off more economically later. The gating surfaces can serve as gauge or reference points for subsequent machining.
Holes and slots
Mould and draught angles are only required in exceptional cases. Only where extremely long inside contours or similar exist it is necessary to provide for a slight conicity or angle.

<table>
<thead>
<tr>
<th>dia. / □ or similar</th>
<th>Holes and channels</th>
<th>Slots and grooves</th>
</tr>
</thead>
<tbody>
<tr>
<td>d (mm)</td>
<td>Through hole</td>
<td>Blind hole</td>
</tr>
<tr>
<td></td>
<td>l</td>
<td>t</td>
</tr>
<tr>
<td>≥ 2 up to 4</td>
<td>≈ 1 x d</td>
<td>≈ 0.6 x d</td>
</tr>
<tr>
<td>&gt; 4 up to 6</td>
<td>≈ 2 x d</td>
<td>≈ 1.0 x d</td>
</tr>
<tr>
<td>&gt; 6 up to 10</td>
<td>≈ 3 x d</td>
<td>≈ 1.6 x d</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>≈ 4 x d</td>
<td>≈ 2.0 x d</td>
</tr>
</tbody>
</table>

Through holes
It is advisable to configure through holes and slots in such a way that they can be formed with an unsplit core slide.

Blind holes
Blind holes and closed slots must be rounded off at the bottom. In the case of Al and Ti alloys, it is advisable to avoid blind holes.

Slots
Slots can only be produced without ceramic cores if the ratio b:t or b:l as indicated in the diagram on the right can be adhered to; The dimension S can be selected as required.

Examples of design measures
The exemplars on the right demonstrate how it is often simple to achieve the economically most favorable table values through intelligent design.
**Flat surfaces**
Although it is possible to cast relatively large surfaces, these should be avoided where possible, as they can only be executed with a dis-proportionate effort. They should consequently be ‘broken up’ by ribbing effects, recessing or breakthroughs. This simplifies the casting process, increases the form strength of the casting under certain circumstances, and often also reduces the weight.

**Knife edges at the casting**
Due to the surface tension of molten metals, it is not possible to cast knives or sharp edges. These must be produced with a machining allowance and then finish ground.

**Knife edges in the tool**
In cases where knife edges would be created in the tool or on the core slide, for example where boreholes with varying diameters collide tangentially with each other, then water-soluble or ceramic cores must be used. However, where this type of transition in the cross-sectional area can be avoided, with a slight adjustment it is often possible to use core slides. This presents a particularly economical solution.

**Division plane and ejector marks**
Where patterns are produced using automatic tools, it can happen that marks are created at the division plane and ejectors; As these are raised areas, as a general rule they can be ignored.
Investment casting are frequently ready-to-mount components without need for subsequent machining. However, where extremely narrow tolerances make this impossible, components may require a machining cycle. Intelligent design can simplify the machining process, so improving overall economy.

**Undercuts**
Undercuts can be arranged in such a way that they eliminate the need for water-soluble or ceramic cores. The knock-out direction in the pattern tool must be taken into consideration here: As the illustration indicates, the undercut determines the knock-out direction.

**Recesses**
Where the functional characteristics of the component so permit, surface which will require subsequent machining can be recessed from the initial casting stage, so reducing the degree of stock removal (and also the workpiece weight).

**Inscription**
Cast company loges, spare part numbers, detents, position and flow marks as well as any other identifying symbols save assembly and downtimes, and help to avoid mistakes when exchanging and ordering spare parts. The type of lettering or identifying mark depends financially on the type of material used: recessed when using soft metals, raised for aluminum or steel tools. If a raised inscription is not possible for functional reason, the inscription field must be recessed and the inscription itself raised. Also for reasons of economy, the lettering should be positioned parallel to the division plane of tool where possible. In case of doubt, a remark in the (enquiry) drawing indicating the possible positions for the inscription field is sufficient. For the nominal height of the lettering, the following regulation applies:

- For Fe, Ni, Co based alloys: $h \geq 22.5$ mm
- For Al and Cu based alloys: $h \geq 2.0$ mm
Material types

The investment casting technique permits the use of an almost unlimited spectrum of casting and also wrought materials. A certain restriction is imposed by the fact that a large number of materials possess similar characteristics and be ‘substituted’ by alternative materials which are at least equivalent in value. On the other hand, investment casting also permits the use of a higher-grade material at no additional cost, so covering a wide range of possible applications. Accordingly, in the following explanation, types providing a representative selection have been specified under the various material groupings. If the use of different materials is stipulated expressly for certain applications, an enquiry is necessary with the producer. The data contained in the tables are guideline values only. This applies also where guaranteed minimum values are specified in standards or other regulations. As a rule, these regulations refer to other shaping techniques unless they explicitly specify the instrument casting method. Unless otherwise indicated, the values apply to separately cast test bars.
Economy
It makes economic sense to work with customarily used investment casting materials. Particular reference is made to these in the following tables. In case of doubt, consult the producer. If at all possible to use corrosion-resistant materials, in particular for small components, in order to eliminate the need for costly surface finishing which is necessary when working with low-alloy and non-alloyed materials. This type of component remains chemically resistant even if the surface is damaged.

It is frequently possible to procure the same components made of different materials - even alloys on a different basis - with one and the same pattern tool. This permits, for example, the material used for identical fittings and pump components to be varied to match the aggressive properties of different media. However, this simple exchange of materials also makes sense in cases where greater levels of different media. However, this simple exchange of materials also makes sense in cases where greater levels of strain occur than were previously known or envisaged. In this case, it is almost always possible to select a more suitable material.

1. Nozzle tips for hot runner injection nozzles used in the plastics industry
   Material: Inconel 713

2. End piece for the steering column of the Fokker F100
   Material: GF-AlSiMg 0.6 wa
   Material number: 3.2384
   Verification of mechanical-technological characteristics is provided through trails from the casting.

3. VDO housing
   Electronic housing for LCD screen used in an armoured defence helicopter PAH2. The part is finish machined. Wall thickness partially to 1.2 mm. Modular system with over 90 ‘movable components’. Material: G-AlSiMg 0.6 wa.

4. Hand lever
   Material: G-AlSi7Mg 0.6 wa
   Material number: 3.2384
   Door opening in the Airbus A330/A340.

5. Bone clamps
   made of implant material 'ZOLLERN SUPER N' CoCrMoN

6. Steering column lever
   Material: G-AlSi7Mg 0.6 wa
   Material number: 3.2384
   Weight: 1350 g
   Foot of the steering column for transmission of mechanical forces in the Do 328

7. Fixed and steering wings for missiles
   made of material 17/4 PH
   Material number: 1.4549
Vacuum investment casting

Due to their chemical makeup, in particular their content of oxygen-affine elements, highly heat-resistant materials have to be smelted and cast under a vacuum.

The vacuum induction investment casting furnace at ZOLLERN is designed as a tandem plant for smelting and casting under vacuum, and intended for the series production of small-scale investment casting. It is specially adapted for the use of preheated ceramic crucible. Gating is performed automatically through a plug hole in the floor of the crucible after a thin metal plate which seals the plug hole has melted through. The metal plate is made of the same material type as the smelted alloy.

The crucible is either made of an oxide ceramic fibre material or forms an integral component of the mould.

The plant operates in the high vacuum range from $10^{-2}$ to 10 m bar, and is capable of producing component sizes of up to approx. 250 mm in diameter and a maximum of 300 mm in height.

The following maximum melting weights can be cast:
- 15 kg of Ni-based material
- 15 kg of Co-based material
- 15 kg of steel alloys
- 15 kg of Cu-based material

The vacuum casting technique additionally offers the benefit of an extremely high degree of purity. Due to the special process technology used, it is also possible to achieved specific grain refinement of castings.

The work sequence at the smelting stations is fully automated with the exception of loading and unloading.

Vacuum remelt alloys exclusively are used as base materials for superalloys.
10 Aluminum electronic housing
for an optical application in the field of laser technology.
Material FG-AlSiMg 0.6 wa
Material number 3.2384
Weight 120 g
The complex internal contour is achieved using various water-soluble wax cores.

11 Cut-away model demonstrating the structural principle of the exhaust gas turbocharger
The turbine wheel (hot side) in the foreground and behind it the compressor area (cold side) with aluminium impeller wheel

12 Aluminium compressor impeller for an exhaust gas turbocharger
Material number 3.2384
Strength values
Rp 0.2 ≥ 270 N/mm²
Rm ≥ 330 N/mm², A5 ≥ 3%

13 Mounting casting for the epicyclic gearbox in the gear system/starter stage of a jet engine
Material 17/4 pH 1.4549
Weight approx. 1500 g
Rm. approx. 1200 Mpa
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