

**TALAT Lecture 3403**

**Designing of Forgings**

17 pages, 18 figures

Basic Level

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**Objectives:**

- to gain an understanding of the interaction between part design, tool design and forging process parameters in order to achieve optimum quality forged products

**Prerequisites:**

- general understanding of metallurgy and deformation processes

**Date of Issue: 1994**

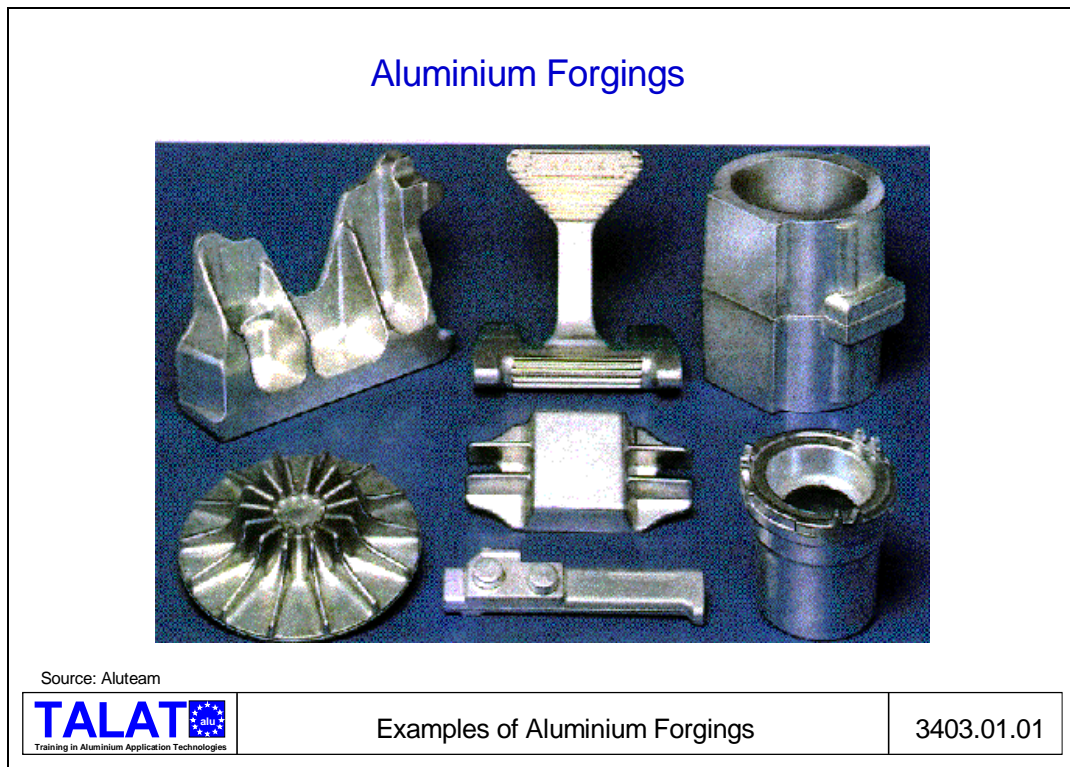
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# 3403 Designing of Forgings

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## 3403.01 Examples of Aluminium Forgings



Aluminium forgings were first used about 60 years ago for the aerospace industry. Since then, there has been a rapid increase of their use in other fields of application. Aluminium forgings are used predominantly in the transport industry, where weight savings lead to savings in fuel consumption.

Aluminium forgings provide the following advantages:

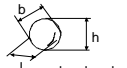




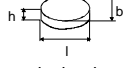










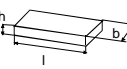

















- high strength and low weight
- good corrosion resistance (for most aluminium alloys)
- the fibre (grain) structure can be arranged to correspond to the main loading direction leading to high strength and fatigue properties

The diagram illustrates some typical forgings, e.g.

- foot pedal for a helicopter
- cuppling flange with undercut
- radial compressor rotor

## 3403.02 Classification of Forms for Die Forgings


Form classifications according to Spies (**Figure 3403.02.01**)

Classification of Forms for Die Forgings							
<b>Form class 1</b> compact form  spherical & cubic parts	Subgroup	101 without extending elements 	102 with one-sided extending elements 	103 with circum- ferential extending elements 	104 with one-sided and circum- ferential exten- ding elements 		
<b>Form class 2</b> disk form  $l \approx b > h$ Parts with round, square & similar contours. Cross parts with short arms, compressed heads on long forms (flange, valve disk etc.)	Subgroup	without extension elements	with hub	with hub and hole	with edge (ring)	with edge and hub	
	Form group	211 	212 	213 	214 	215 	
	22 disk form with double-sided extension element 	222 	223 	224 	225 		
<b>Form class 3</b> Long form  $l > b \geq h$ Parts with elongated axis. Length groups: 1 short part $l < 3b$ 2 half-length parts $l = 3 \dots 8b$ 3 long parts $l = 8 \dots 16b$ 4 very long parts $l > 16b$ (Digits of long groups added as suffix after slash, e.g. 334/4)	Subgroup	without extension elements	with extension elements symmetrical to axis of main form element	with open or closed forks	with extension elements unsymmetrical to axis of main form element	2 or more different extension elements of similar size	
	Form group	31 Main form element with straight long axis 	312 	313 	314 	315 	
	32 long axis of main form element curved in one plane 	321 	322 	323 	324 	325 	
	33 long axis of main form element curved in more than one plane 	331 	332 	333 	334 	335 	

Source: K. Spies

Forgings are classified according to their geometry in different groups. The Spies form classification serves as a help for the layout of die forging operations.

Starting backwards from the final form required, this form classification can be used to ascertain the starting form and the intermediate form.

Classifications of Forms for Die Forging		
Form class 1 and 2:	Forgings with few extension members Forged directly from rod sections	
Form class 3:	Forging without intermediate forms if the preformed stock matches the final form.	
The number of intermediate forms depends on:		
- the formability of the material		
- the complexity of the workpiece geometry		
- the number of forgings		
Source: K. Spies		
	Form Classification According to Spies	3403.02.02

Merits of the classification system by Spies:

- A clearly arranged representation using 3 classes of forms. The sub-groups are determined by the number, type and geometry of the secondary form elements (see **Figure 3403.02.02**).

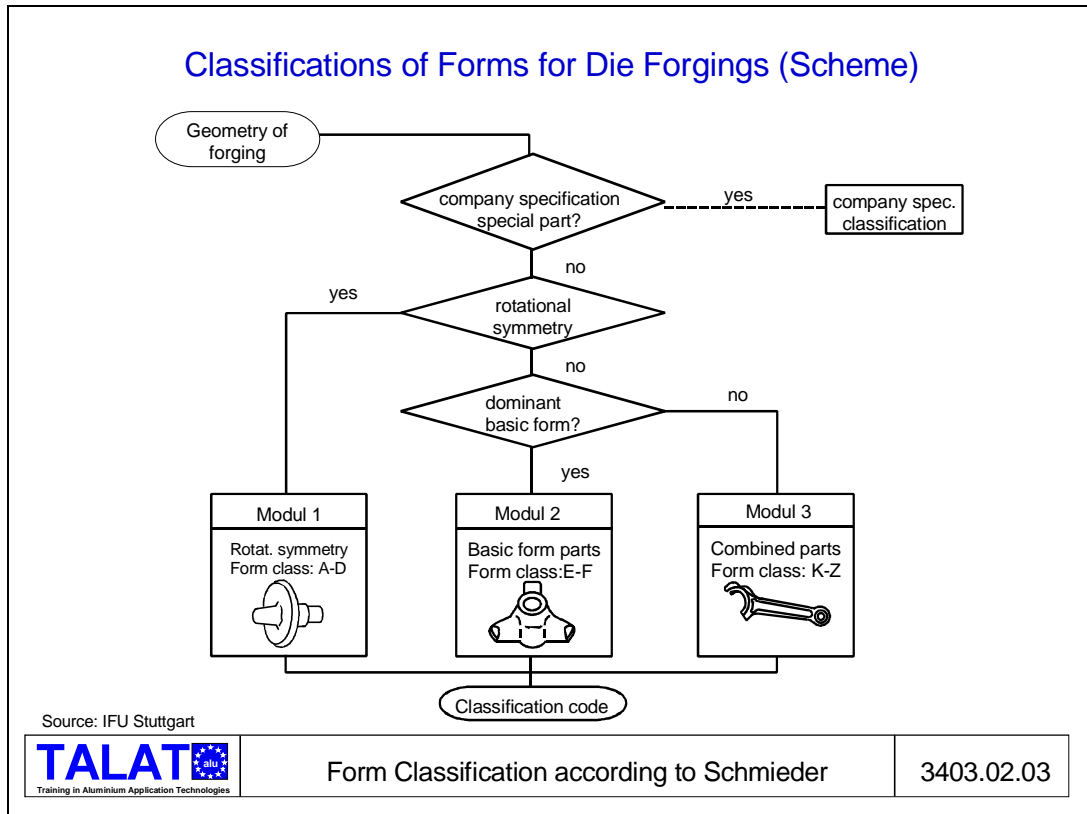
Shortcomings:

- All combinations cannot be considered.
- No difference is made between axially symmetrical and non-symmetrical workpieces.

For an alternative classification of forms see **Figure 3403.02.03**. This modular form arrangement according to Schmieder is planned for use in data base systems for computer assisted planning of intermediate forms with CAD interface.

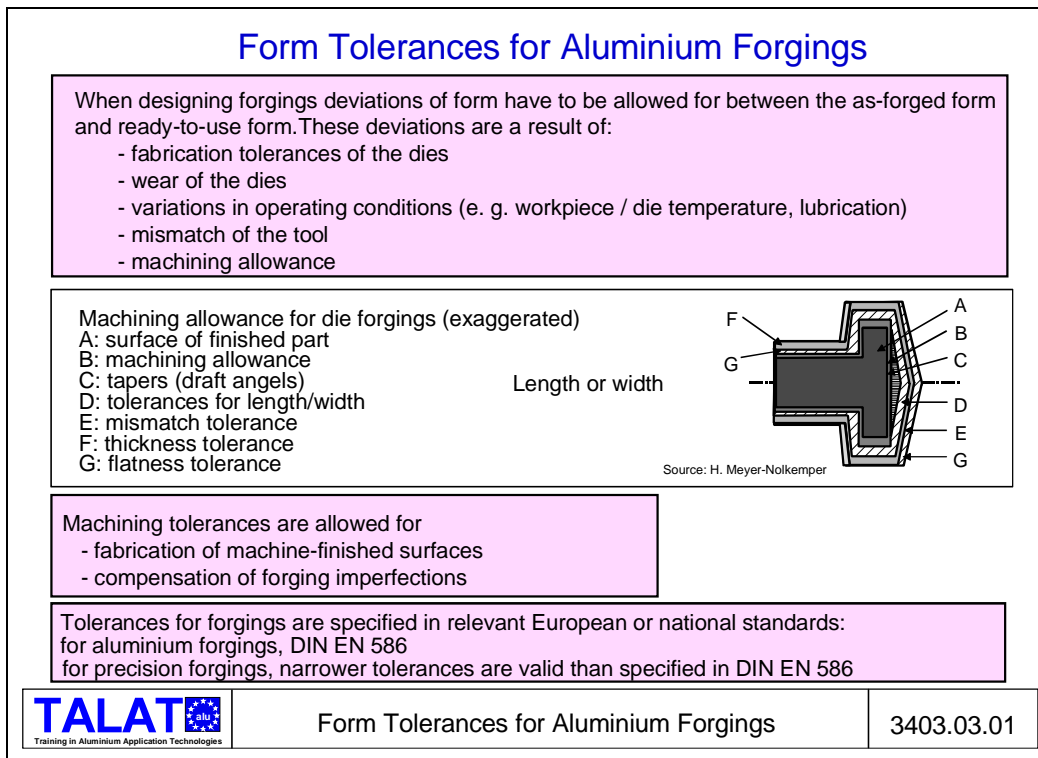
The workpiece is described using a 6-figure alpha numerical code. The features of this classification are:

- Classification in 3 independent regions:  
rotation parts, basic form parts, combined parts
- Form elements are abstracted, i.e. the workpiece is broken down into different basic forms.
- Further characteristics for the classification are the form and direction of the main axis of the individual components.



## 3403.03 Tolerances for Aluminium Forgings

Figure 3403.03.01 shows the tolerance allowances in a forging.



The difference between the final form and the forged form is a result of:

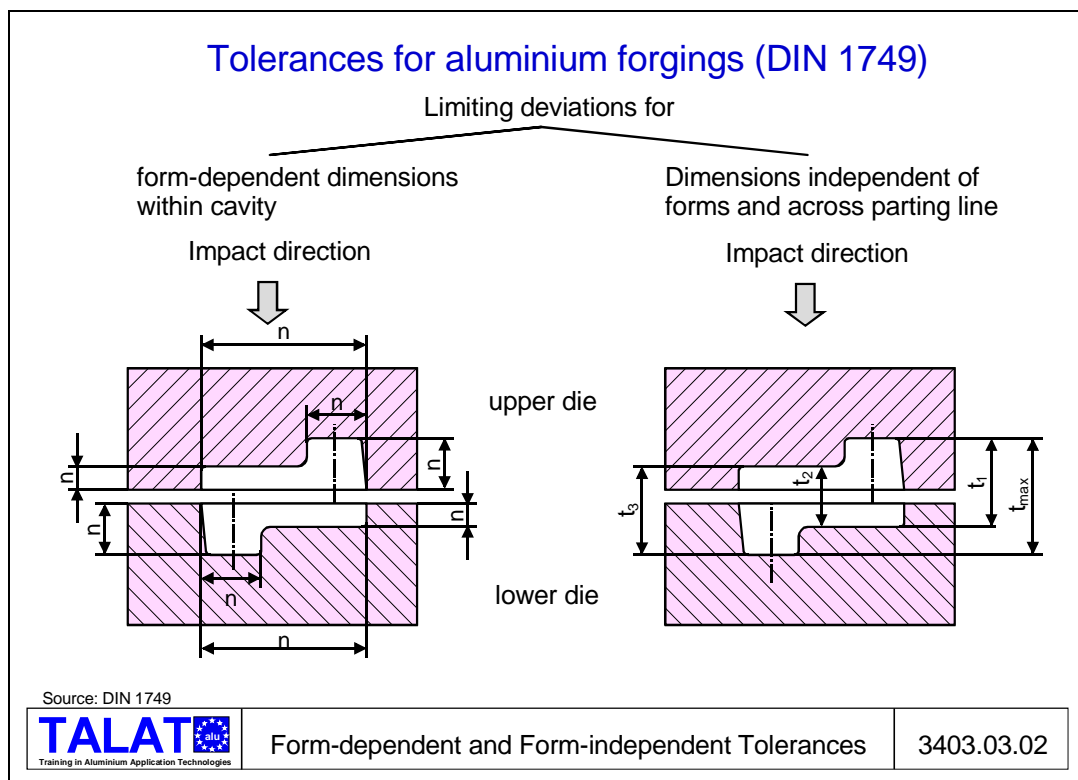
- Fabrication defects of die (die tolerances),
- wear of die,
- deviations in the production parameters (temperature),
- mismatch of upper and lower die and
- machining allowances.

After the forming process, the allowances are machined off. Machining may cut into the fibre structure.

**Figure 3403.03.02** illustrates the dimensions which determine the geometric tolerances for aluminium forgings. The geometric tolerances in aluminium forgings are divided into form-dependent and form-independent dimensions (according to DIN 1749, EN 586 part 3 (draft)).

Form-dependent dimensions depend only on the geometry of the die cavities. These vary with the nominal size.

Form-independent dimensions depend additionally on the closure and flash extension of the die. They depend on the nominal size and content of the projected cross-sectional area.



Tolerances for form-independent dimensions are, as a rule, larger than for form-dependent dimensions.

## 3403.04 Design Rules

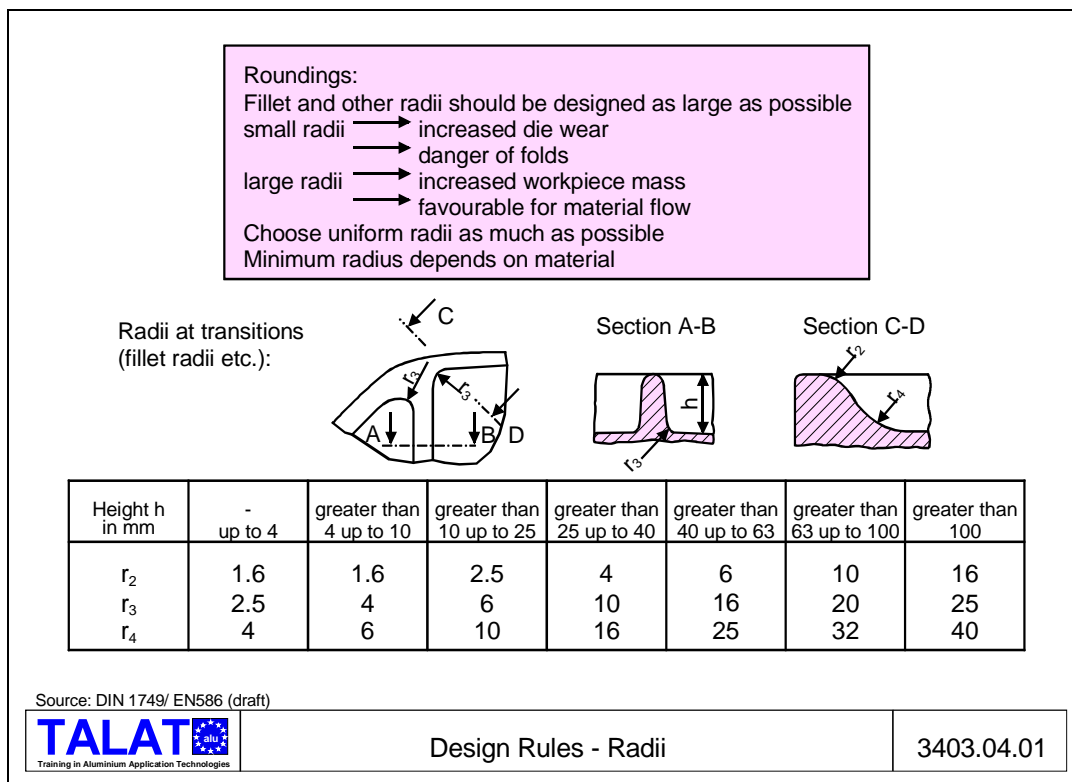
**Figure 3403.04.01** summarizes design rules for radii in aluminium forgings according to DIN 1749 and EN 586 part 3 (draft).

Radii in the die cavities influence:

- grain flow
- forging load
- die wear
- strength properties of forged part

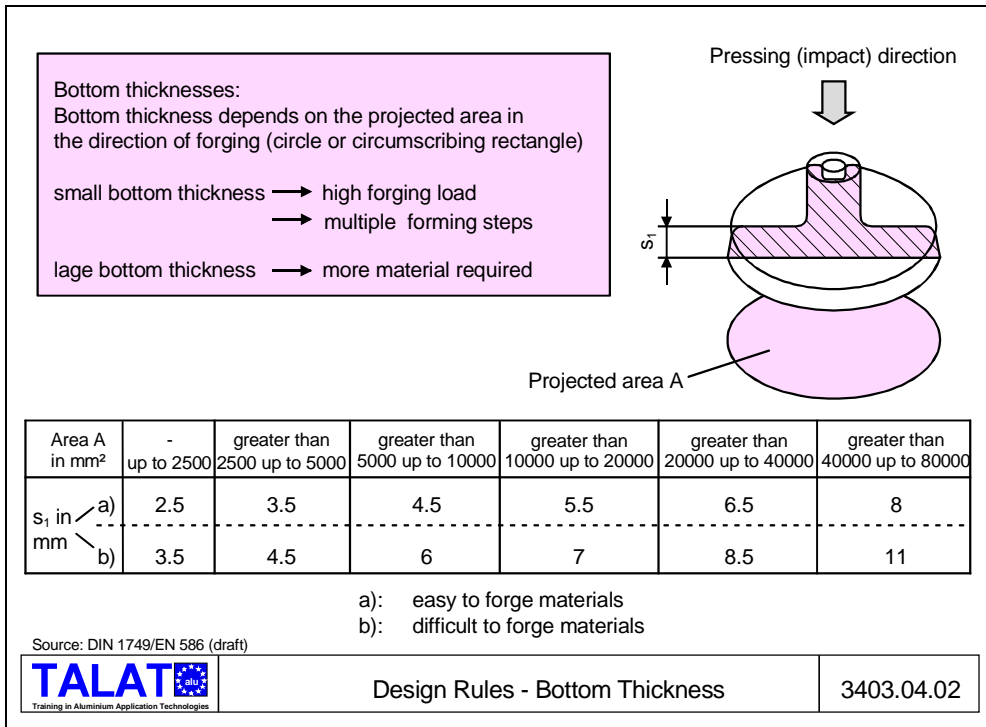
The size of the radius depends on the form elements, e.g., fins or side walls and on the type of forging process. The table shows guide values according to DIN 1749 for dimensioning the radii:

- $r_2$ : radius of die cavity edge
- $r_3$ : fillet radius for fins
- $r_4$ : fillet radius for side walls



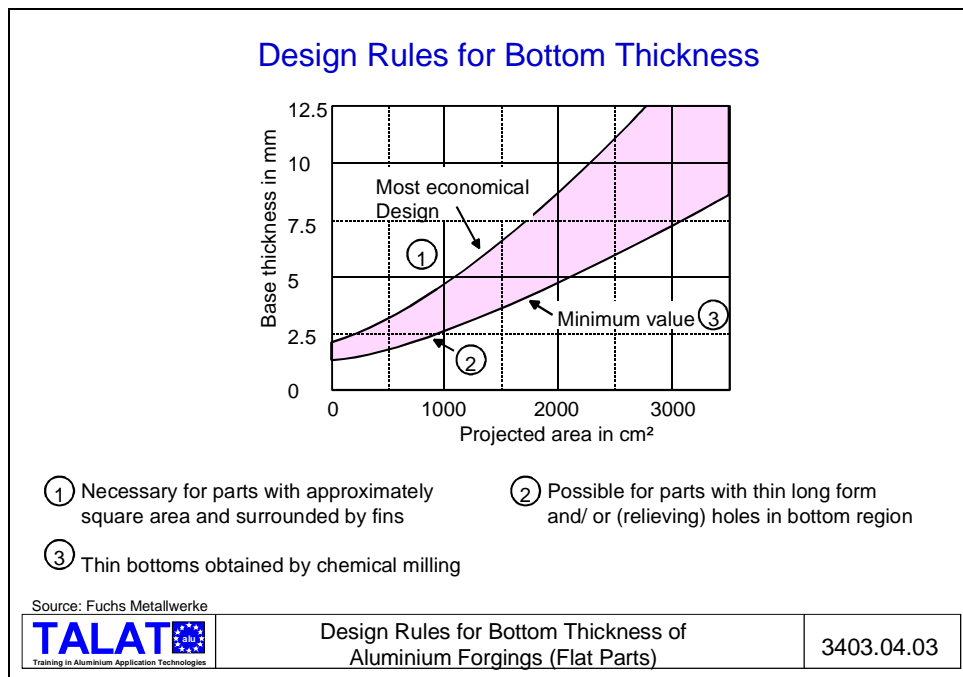
**Figure 3405.04.02** gives recommendations for the bottom thickness of forged aluminium parts according to DIN 1749 or EN 586 part 3 (draft). The thickness of the bottom influences the forging load. For a low bottom thickness, a number of forming steps could, in some cases, be necessary. The thickness of the base depends on the projected surface of the workpiece in the pressing direction and the forming properties of the material.



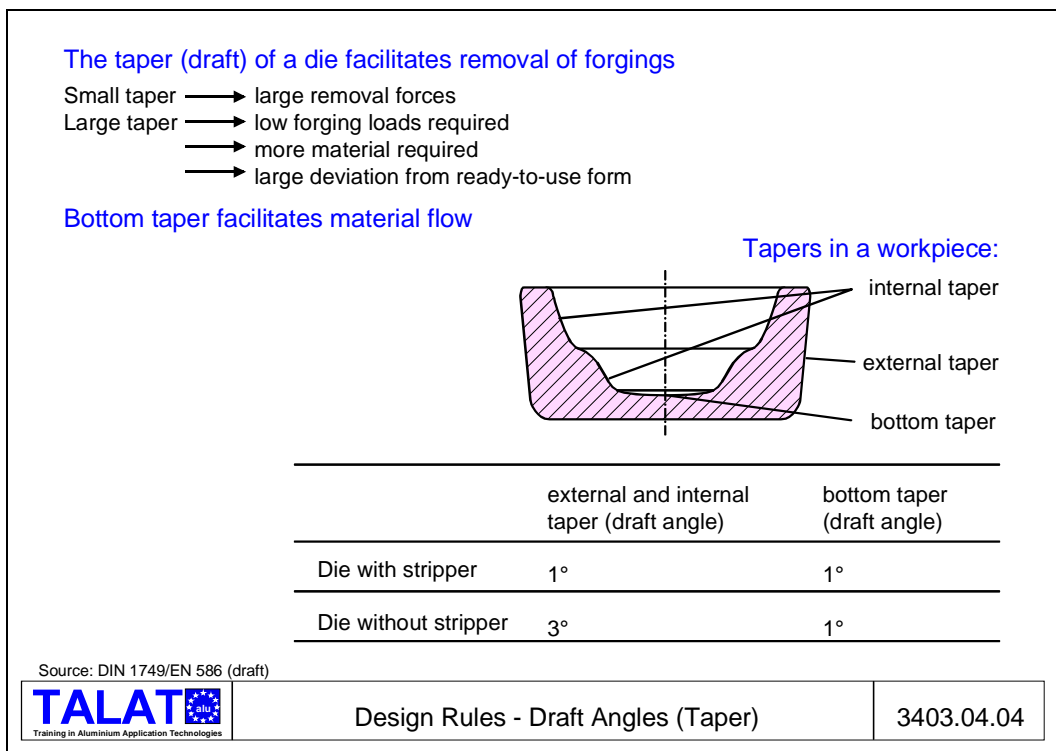


**Figure 3403.04.03** shows practical recommendations for the bottom thickness of mainly large forged parts. The geometry of the forging - long, thin parts or parts with square cross-section - also influences the base thickness. The diagram shows recommended values for:

- minimum values (high forging load, low amount of material, in some cases no machining required),
- the most economical design.
- small bottom thicknesses can be produced by chemical milling.



**Figure 3403.04.04** contains design rules with respect to draft angles (tapers) according to DIN 1749 or EN 586 part 3 (draft). Draft angles facilitate the removal of forgings from the die. A large draft angle ( $3^\circ$ ) facilitates forming. When designing draft angles, the die type - with or without stripper - should be considered. The base is also drafted to facilitate the material flow. The tolerances for drafting depend on the dimensions of the forging.



## 3403.05 Dimensional Precision of Die Forgings

**Figure 3403.05.01** tabulates a comparison of precisions obtained with different production processes.

IT 6 and 7 can be obtained by die forging only in exceptional cases. Values normally attainable are IT 12 to IT 16.

Under special conditions, even IT 8 can be attained (precision forging).

### Precision of forgings

Precision available with different forming and machining processes																
Fabrication process	Dimensions	IT quality														
		5	6	7	8	9	10	11	12	13	14	15	16			
die forging	diameter		■	■	○	○	○	○	○	●	●	●	●	●		
hot extrusion	diameter							○	○	●	●	●	●	●		
cold extrusion	diameter		○	●	●	●	●	●	●							
stamping to size	thickness			○	●	●	●	●	●	●						
turning	diameter		○	●	●	●	●	●								
milling	thickness		○	●	●	●	●	●	●	●						
round grinding	diameter	●	●	●	●	●										

● normally attainable    ○ attainable through special measures    ■ attainable in exceptional cases

Source: H. Meyer-Nolkemper

	Precision Attainable in Die Forgings	3403.05.01
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**Figure 3403.05.02** lists measures to improve the precision of die forgings. Improving the dimensional accuracy leads to precision or high precision forging. For this purpose, extra care must be taken during each individual step of the forming process.

The measures used depend on the listed sources of defects and describe the steps recommended for the individual influencing parameters.

	Starting form, separating	Heating	Tool	Machine
<b>1. Dimensional deviations</b> 1.1 form dependent dimension (l,b,d)  1.2 form independent dimensions(h)  1.3 Misalignment	(b) temp. stability, furnace control, constant stroke	(d) constant end temperature, constant stroke, intermediate heating (e) intermediate form calibration	precision of fabrication, low wear, constant temperature (30 to 40 °C below forming temp.)	hydraulic pressing for easier control
	(a) mass dosage, closer tolerances for semis, precise vol. cutting	as in b)	as in (d) intermediate flash removal, etching & magna-flux inspection, then reforging in the final die cavity	low spring-back
				precise assembly, clamping
<b>2. Deviations betw. raw/finished form</b> 2.1 low base thicknesses 2.2 narrow ribs 2.3 small corner radii 2.4 small taper	as in a)	as in e)  as in e)	lubrication low edge wear stripper	
<b>3. Surface defects</b>			cleaning die cavity, low wear of die cavity	

Source: H. Meyer-Nolkemper

	Measures to Improve the Precision of Die Forgings	3403.05.02
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**Figure 3403.05.03** illustrates a precision forged part of an aeroplane door in a honeycomb construction. In the part forged with a drafting angle of  $0^\circ$ , only holes have still to be drilled or cleaned. The front flash, designed to relieve the die, must still be removed.

### Precision and High-Precision Forgings

Example of a precision forging

Source: H. Meyer-Nolkemper

Narrow tolerances apply to precision forgings:

- Tapers:  $0 - 0.5^\circ$
- Length and width tolerance: 50 %
- Thickness: 60 %

High-precision forgings - almost "ready-to-use" parts

High-precision forgings are used to

- increase the accuracy of the structural part
- increase the fatigue strength
- reduce the mass of the component
- reduce the finish-machining required
- improve the economy

Precision Forging

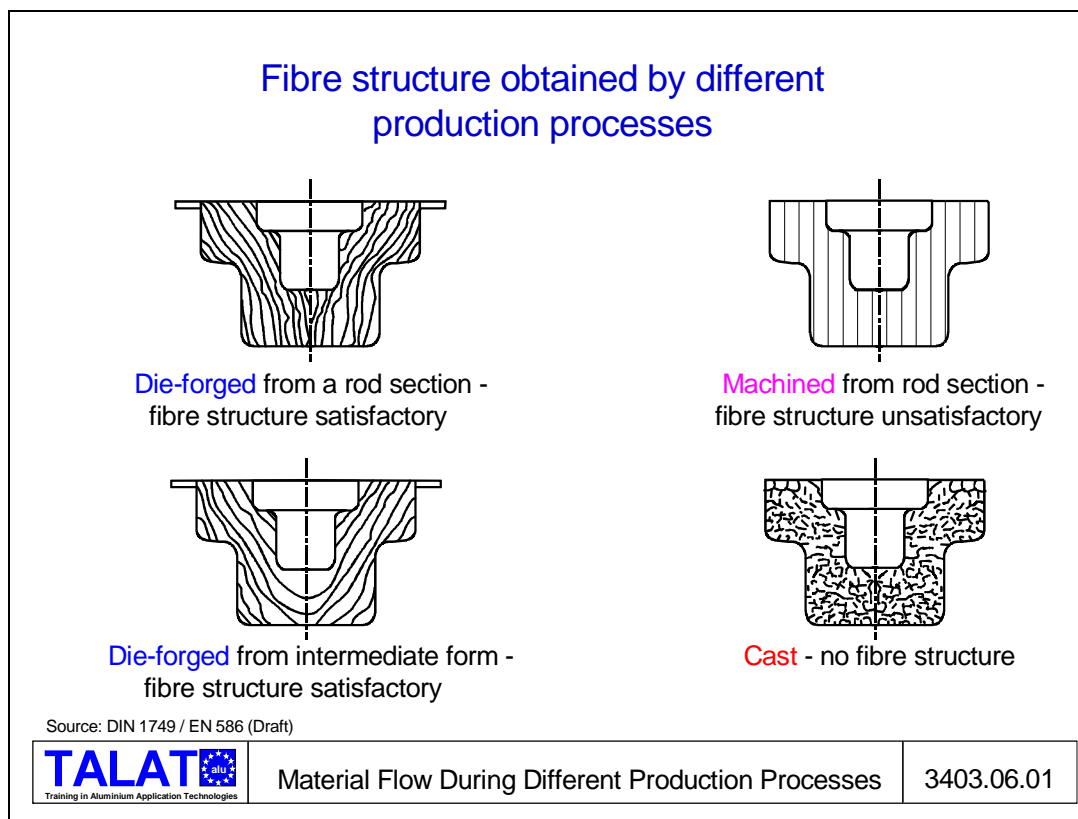
3403.05.03

High precision forging is a special case of precision forging. In precision forging, the accuracy and surface quality are of such a high quality that at least one operational step can be saved. In high precision forging, the **ready-to-use components** are produced with an accuracy which can be attained otherwise only by machining. High precision forgings are designed keeping the following aspects in mind:

- Increasing the accuracy of the component
- Increasing the fatigue strength
- Reducing the mass of the component
- Reducing the amount of machining
- Increasing the economy

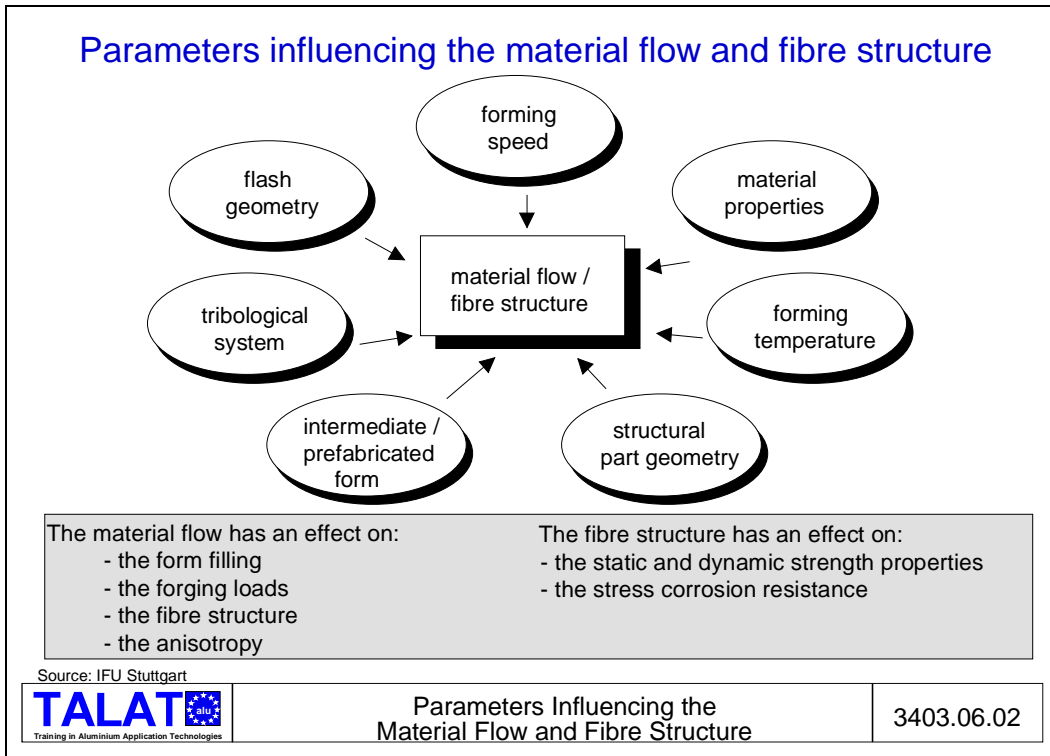
### 3403.06 Designing for Material Flow and Grain Structure

**Figure 3407.01.01** illustrates an example for the grain (fibre) structure in the longitudinal direction for different fabricating processes. During forging, an attempt is made to create a fibre structure corresponding to the main loading direction. Castings do not exhibit a fibre structure. During fabrication by machining of an extruded semi-product, for example, individual fibres are cut. This leads to a reduction of the fatigue strength. The fibre structure depends to a large extent on the type and form of the starting material. Because of the good extrudability of aluminium, it is advisable to use extruded sections as pre-fabricates for the forgings. The final part then exhibits a mixed fibre structure.



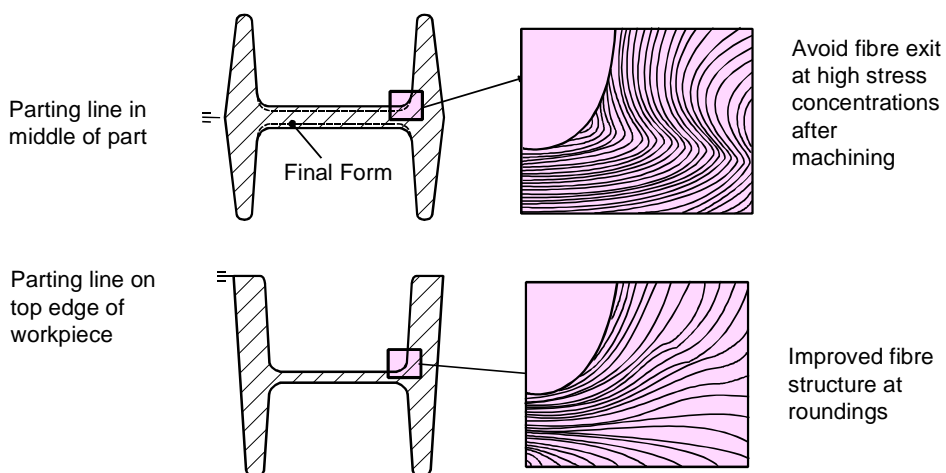
**Figure 3403.06.02** shows the most important parameters which have an influence on the material flow during forging. The type of material flow itself affects a number of forming parameters and index values of the workpiece.

The fibre structure affects the statical and dynamical strength properties in particular, as well as the stress corrosion properties of certain alloys (AlZnMgCu).



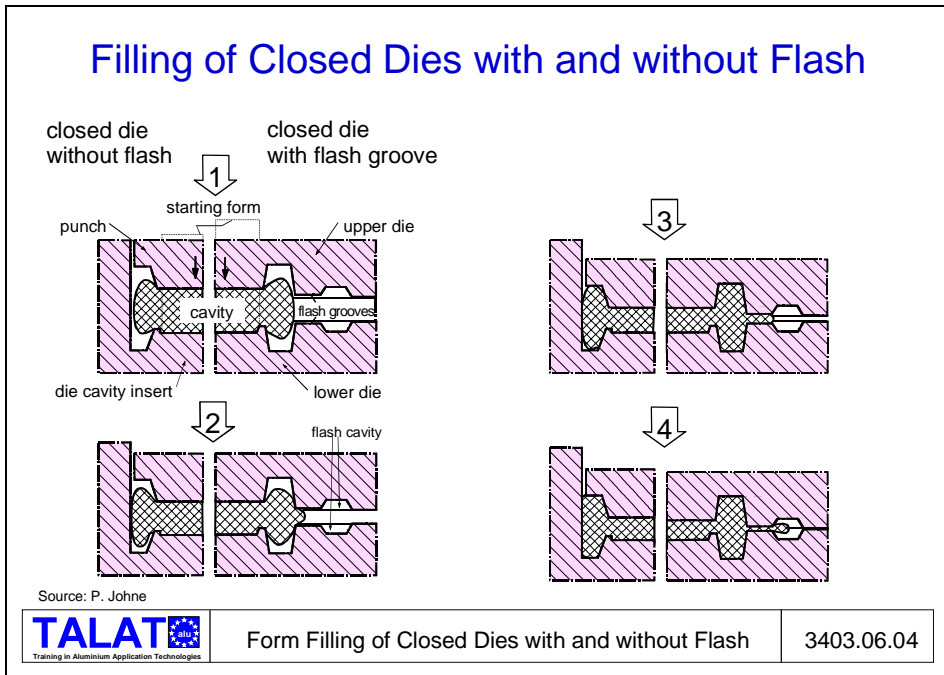
The position of the parting plane of the tool has an influence on the material flow during forming (see also Figure 3402.03.04). **Figure 3403.06.03** illustrates how the material flow and consequently the fibre structure can be improved by shifting the parting plane from the middle of the section to the top. The section of the modified die parting shows a more uniform fibre structure at the rounding.

### Effect of Die Parting on the Material Flow



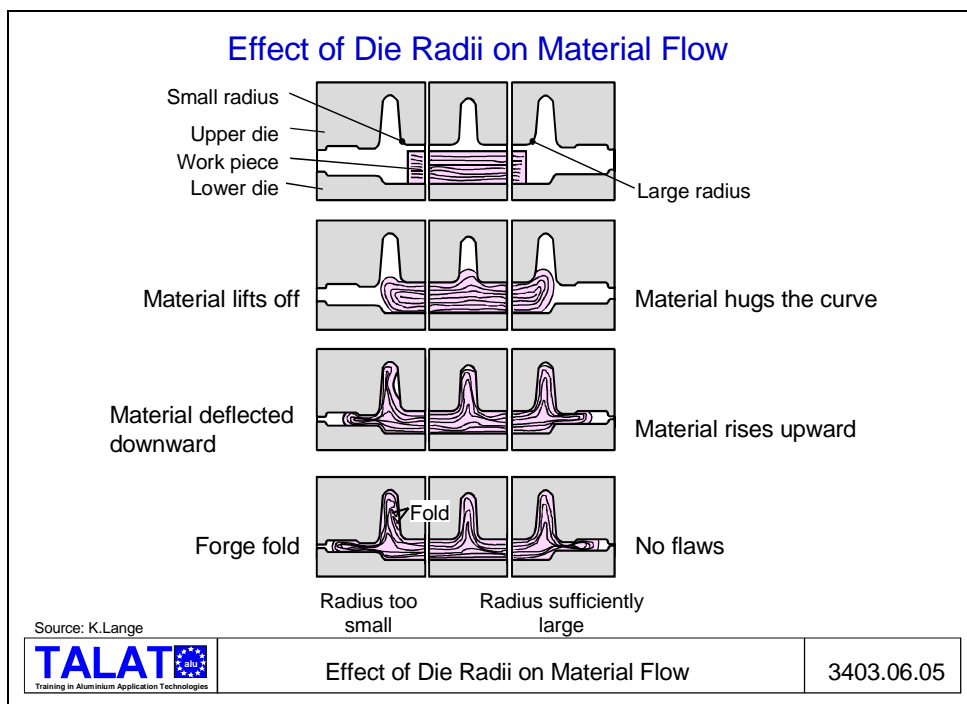
Source: H.Meyer-Nolkemper

	<b>Effect of Die Parting on the Material Flow</b>	<b>3403.06.03</b>
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**Figure 3403.06.04** illustrates the process of form filling in closed dies with and without flash. During forming in dies with flash, the extra material is pressed out of the die cavity into the flash or flash cavity. The geometry of the flash gap has a deciding influence on the forging load and the form filling of the die cavity.

During forging without flash, the whole material remains in the die filling it out completely. Both, forging stock and finished forging, have to have identical masses. The material flow is controlled by the geometry of the raw stock, the flow stress and the tribological conditions at the contact zone of the die.



**Figure 3403.06.05** shows the effect of increasing die radii on material flow during die filling. Folds can be effectively avoided.

The schematic diagram illustrates, how the material flow is affected by the design of the fillet radii (see also **Figure 3403.04.01**, Design rules - fillets). When the radii are chosen properly, the material hugs the radius of the die cavity during forming and then flows up along the walls. If the radius is too small, then the material pulls away from the die cavity, coming to rest on the opposite wall from where it then rises up. On reaching the top of the cavity, the material is redirected downwards and fills out the cavity. Consequently, cold shuts form and laps occur where the redirected material glides over the material flowing up from the bottom leading to a high loss of strength properties at this location.

### **3403.07 Literature**

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