TALAT Training in Aluminium Application Technologies

TALAT Lecture 3706

Bending and Folding

16 pages, 19 figures

Basic Level

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Objectives:

– to describe the fundamentals of bending and folding aluminium sheet
– to describe different methods in design of folding tools

Prerequisites:

– General background in production engineering and sheet metal forming
– TALAT Lectures 3701, 3702, 3703, 3704, 3705

Date of Issue: 1996

3706 Bending and Folding

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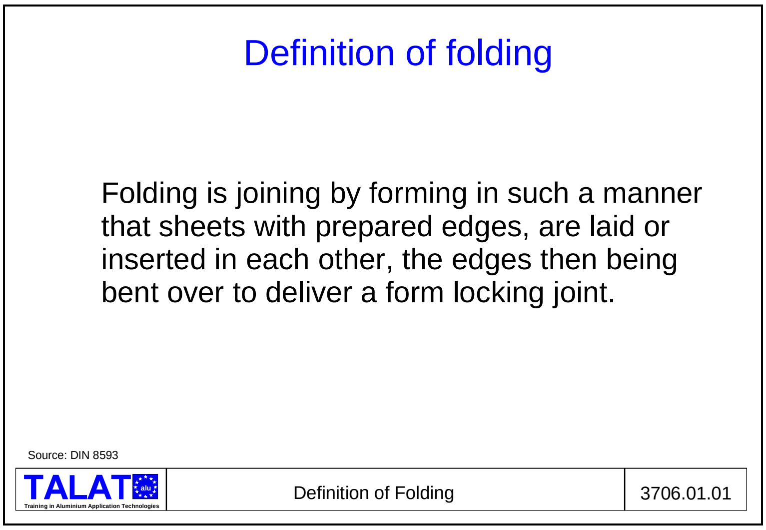
3706.01 The Folding Process

Definition of folding

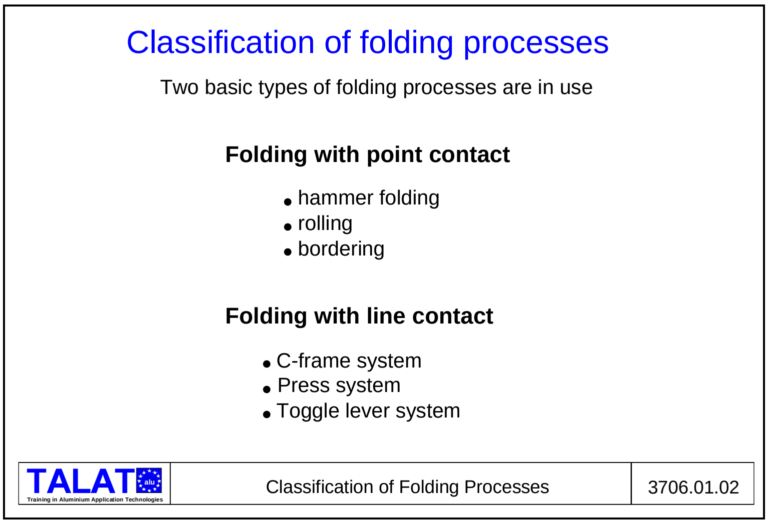
In DIN 8593, part 5, folding is defined as "joining by forming in such a manner that sheets, which have been prepared at their edges, are laid or inserted in each other, the edges being then bent over to provide a form locking joint" (**Figure 3706.01.01).**



Classification of Folding Processes

Two basic types of folding processes are most frequently used **(Figure 3706.01.02)**:

- folding with point contact, e.g. hammer folding, rolling and bordering
- folding with line contact, e.g. toggle lever system, C-frame system and press system.



Fields of Application of Folding

Figure 3706.01.03 lists the classical field of application of folding: in the packaging industry (e.g. cans and beverage cans), in equipment construction (e.g. for ventilation canals, in ventilation chutes, for metallic roof planking), household goods industry (e.g. refrigerators, washing machines), in automobile construction for parts like doors, bonnets and booth covers and generally for obtaining smooth edges or as edge stiffeners.

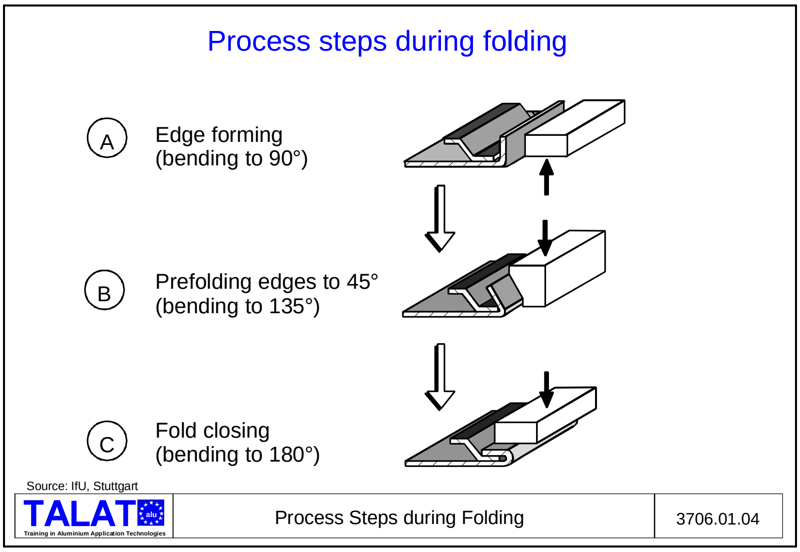
Fields of application of folding

Packaging industry	- e.g., cans and beverage cans
Equipment construction	- eg., ventilation canals, metallic roof planking
Household goods	- e.g., refrigerators, washing machines
Automobile construction	- e.g., doors, bonnets
Others:	-e.g., obtaining smooth edges, edge stiffeners

Source: IfU, Stuttgart

TALAT Training in Aluminium Application Technologies | Fields of Application of Folding | 3706.01.03

Process Steps during Folding



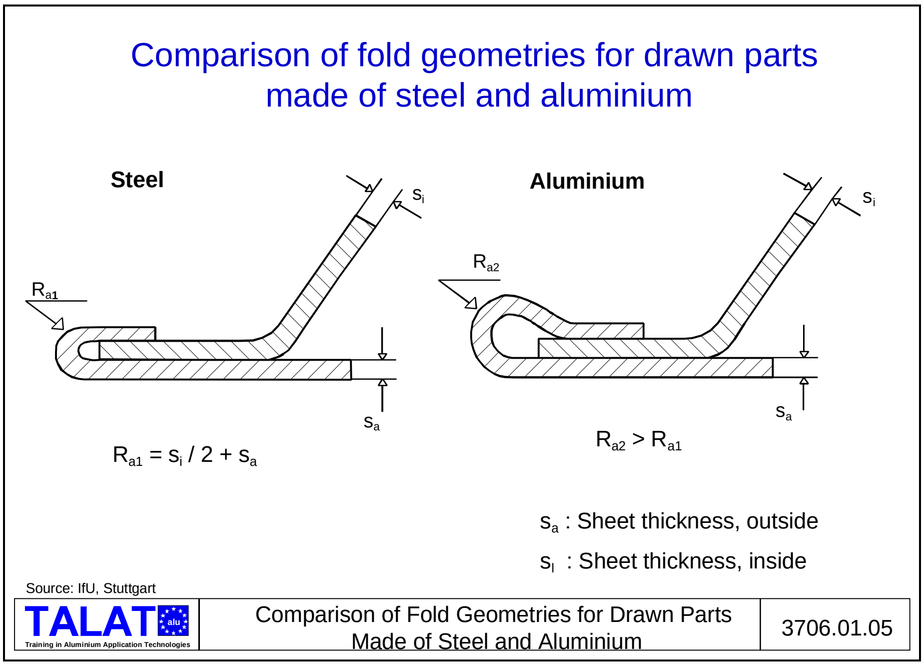
Body parts are mostly folded in presses, in which the forming operation is carried out over the whole rim of the part in two or three steps, unlike the partial round folding of cans. The principle steps of the operation are shown in **Figure 3706.01.04.** In the first step, the edges of the outer radii are bent to 90°. In the second step, the edge is bent another 45° (bending to 135°, prefolding). In the third step, the fold is press closed (bending to 180°, finished fold).

Comparison of Fold Geometries for Drawn Parts Made of Steel and Aluminium

There is a difference in the forming behaviour of aluminium and steel, the former metal being characterised by

- a lower reduction in cross sectional area at rupture,
- a lower ability to accommodate stress concentrations and
- a lower limit curve in the formability limit diagram (FLD).

Consequently, the experience gained with steel sheets cannot be fully transferred to aluminium sheets. For example, while folds in steel sheets can be pressed closed, larger radii bends are required for aluminium alloy sheets. This type of fold is called a "bead fold" or „rope hem“, see **Figure 3706.01.05**.



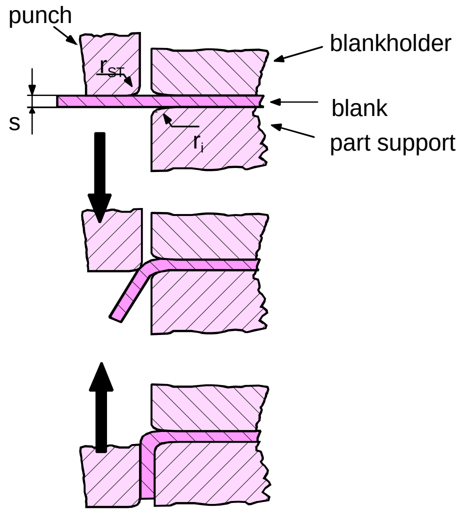
In summary, steel and aluminium have different forming behaviours which make it necessary to use different designs for folding tools.

3706.02 Bending and Springback in the Folding Process

The Bending Process

Folding consists of three bending operations: down-flanging to 90°, bending from 90° to 135° and finally finishing from 135° to 180°. In the standard down-flanging operation the part is clamped on one side. The punch moves downward (or upward) forming the flange over a predetermined inner bend radius r_i, see **Figure 3706.02.01**.

The bending process



Source: IfU, Stuttgart

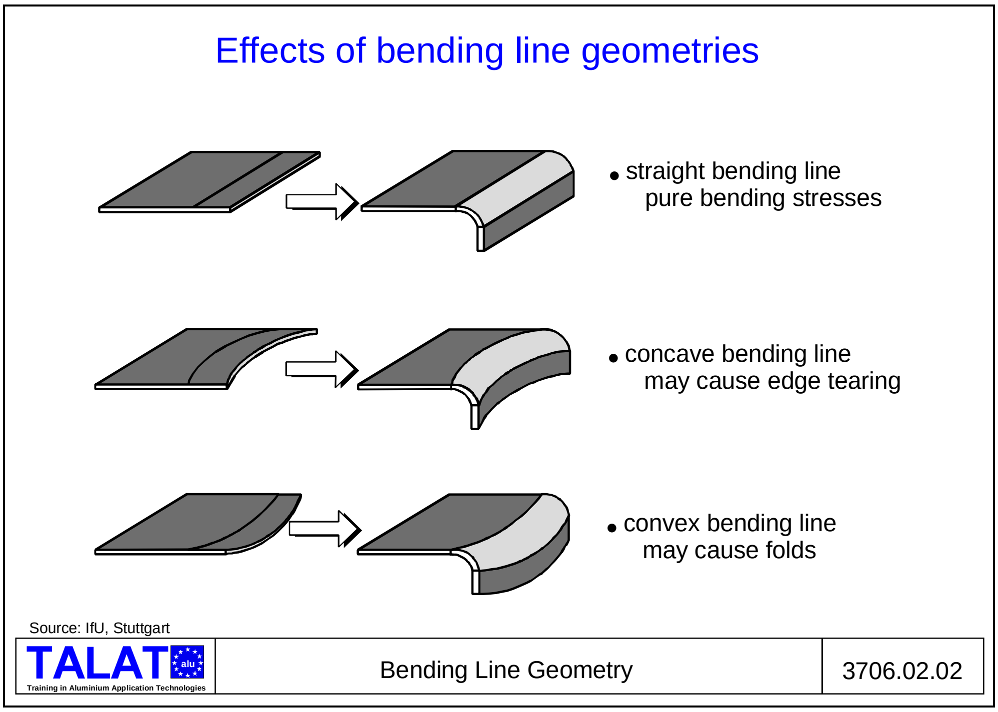
TALAT Training in Aluminium Application Technologies | The Bending Process | 3706.02.01

Bending Line Geometries

During bending along a straight bending axis, pure bending stresses occur. In practice, however, the sheet parts to be folded seldom have a straight contours; curved contours occur most often, see **Figure 3706.02.02**. During bending around curved edges, the bending stress is superposed on tensile and compressive stresses.

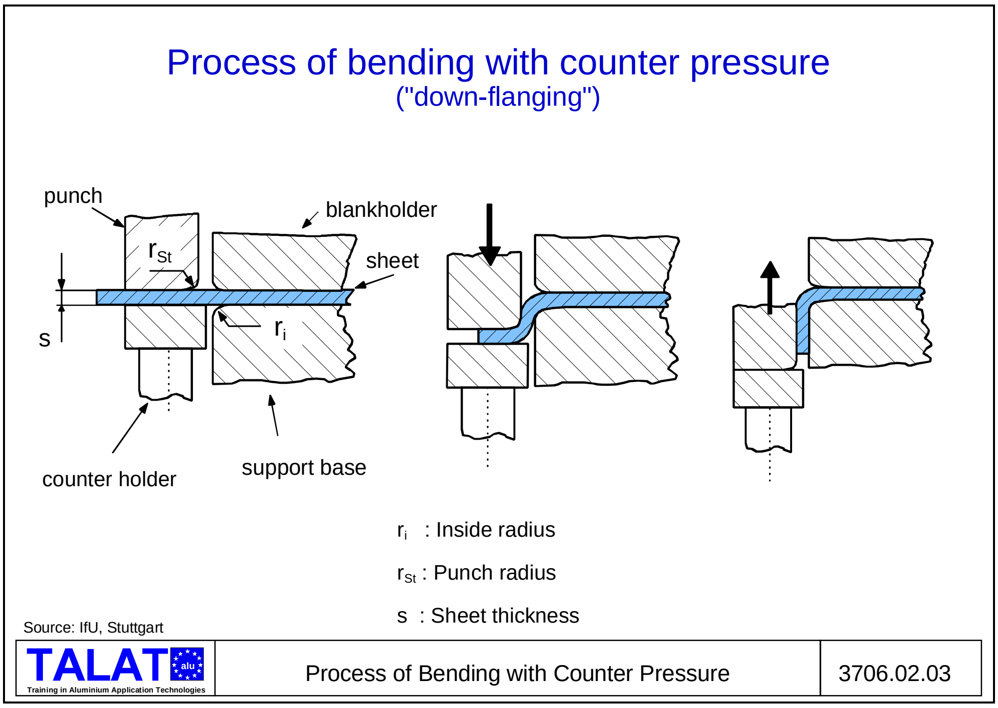
The following types of bending line geometries exist:

– Straight bending line: In this case one has a pure bending stress.
– Concave bending line: Here bending stresses occur together with tensile stresses, which could cause the sheet edges to tear.
– Convex bending lines: The combination of compressive and bending stresses can lead to formation of wrinkles in the down-flange.



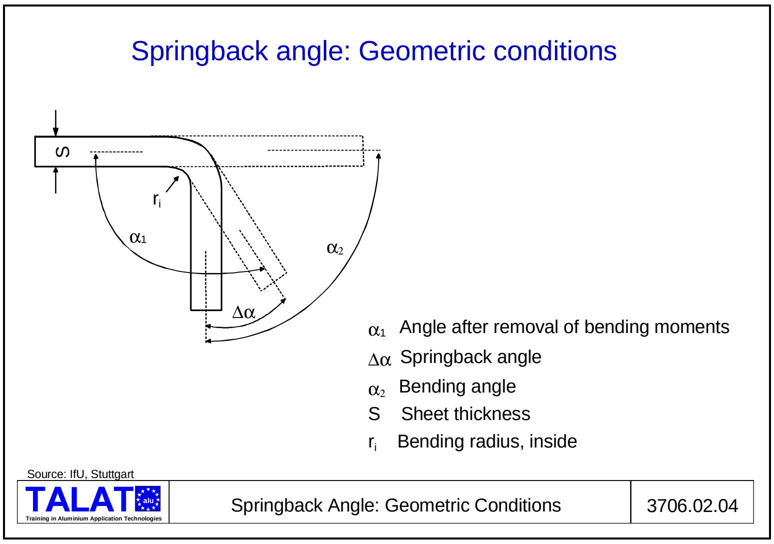
Process of Bending with Counter Pressure

During bending with counter pressure (e.g. press-brake with bottoming die) the sheet blank is bent between a punch and a bottoming die, see **Figure 3706.02.03**. The punch moves downward, till the sheet blank is completely enclosed between the punch and bottoming die. This hinders the formation of folds in convex line bending. In general, the application of the counter pressure reduces the springback and minimises tearing when bending along a concave line.



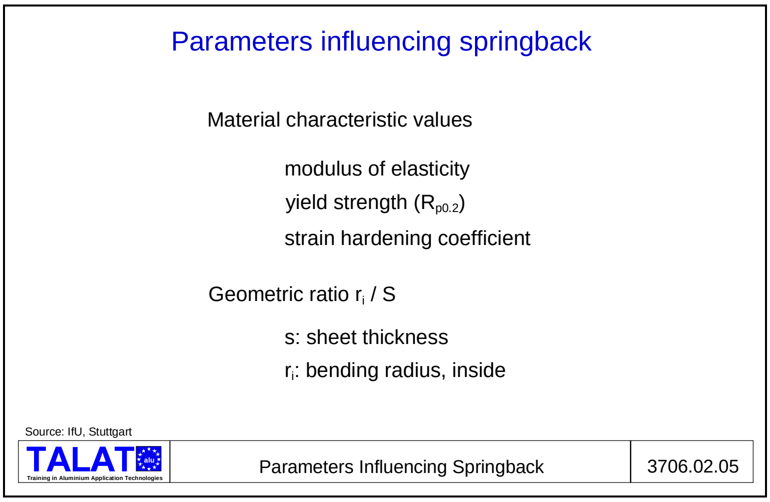
Springback Angle: Geometric Relationship

Springback and tearing are important sources of failure during bending operations. Springback is a result of the elastic-plastic forming behaviour of the material. After removal of the bending moment which produced a bending angle of α_2, the sheet springs back by an angle of $\Delta\alpha$, see **Figure 3706.02.04**. Springback can be reduced or compensated for by the proper use of material and tool technology.



Parameters Influencing Springback

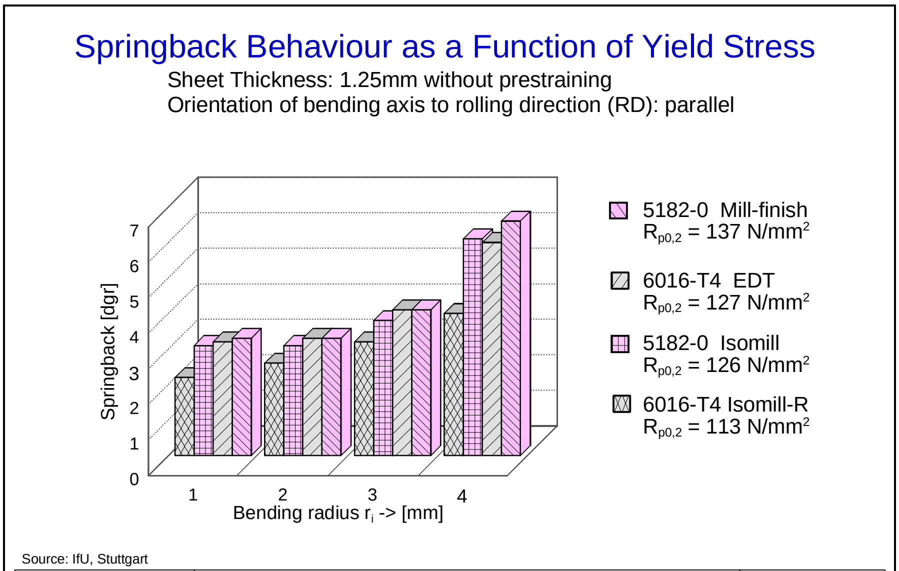
The main parameters influencing springback are listed in **Figure 3706.02.05.** By changing the material characteristic values, e.g. increasing the modulus of elasticity and decreasing the yield stress and strain hardening coefficient, the springback can be minimised.



By proper choice of the geometrical ratio the smallest bending factor r_i/s can be determined for which failure is not encountered and the springback is minimum.

Springback Behaviour as a Function of the Yield Stress

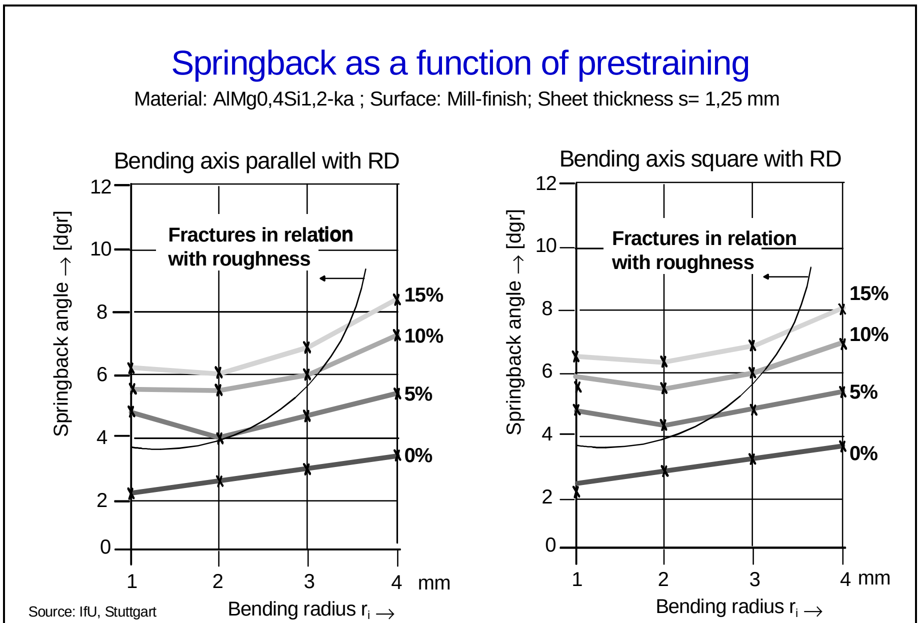
The example in **Figure 3706.02.06** shows the influence of yield stress on the springback behaviour. For constant sheet thickness (*s* = 1.25 mm) springback increases with increasing yield stress and with increasing bending radius .



TALAT | Springback Behaviour as a Function of Yield Stress | 3706.02.06

Springback as a Function of Pre-straining

The springback angle of prestrained sheets depends on the degree of prestraining and the hardening, **Figure 3706.02.07**. The samples shown here were prestrained to 5 %, 10 % and 15 % before being bent to radii of 1, 2, 3 and 4 mm.



TALAT | Springback as a Function of Prestraining | 3706.02.07

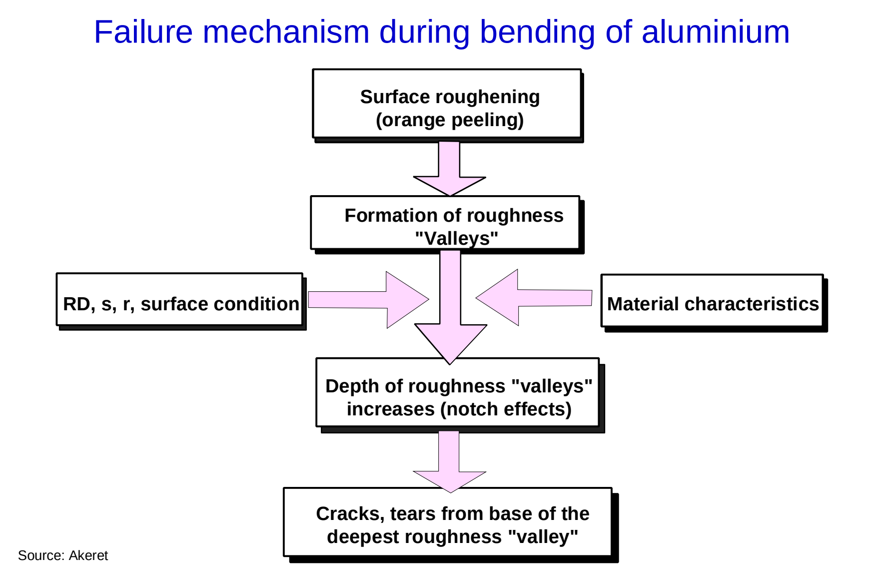
It is clearly evident here that the springback also depends on the position of the bending axis with respect to the rolling direction. For the sheets in mill finish condition shown here, the springback angle is higher when the bending axis is at 90° to the rolling direction than when it is parallel to the rolling direction.

The increase in springback with 1 mm bending radius and additional prestraining is a result of the formation of cracks.

Failure Mechanism during Bending of Aluminium

The formation of cracks in the outside fibres subjected to tensile stresses during bending is considered to be the failure criterion. Akeret describes the failure mechanism during bending as follows: The start of the bending process is accompanied by a roughening of the surface (orange peeling) which gets more pronounced as the bending proceeds, thus forming deeper surface valleys which produce notch effects, thereby initiating cracks which finally cause failure, see **Figure 3706.02.08**.

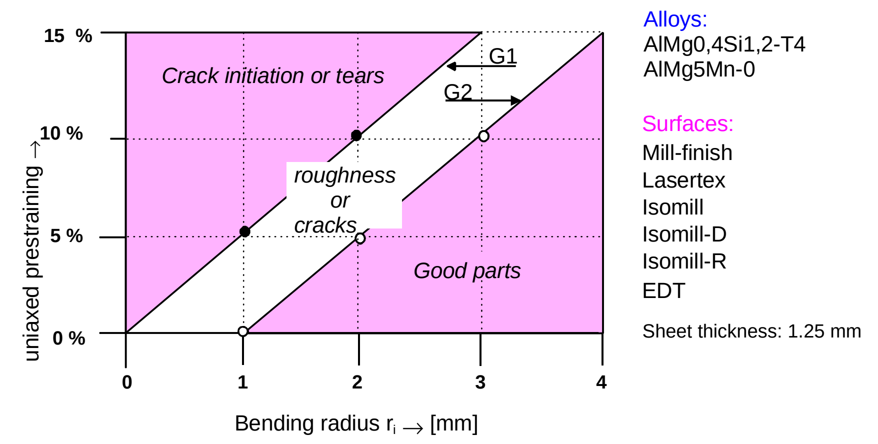
The tearing behaviour is influenced by the material characteristic values, sheet thickness, bending radius, rolling direction and the surface structure.



TALAT Failure Mechanism During Bending of Aluminium 3706.02.08

Tearing Behaviour as a Function of Pre-Straining

Figure 3706.02.09 illustrates the tearing behaviour as a function of the degree of (uniaxial) prestraining and the inner bending radius. Above the straight line G1, i.e. at small bend radii and high degrees of prestraining, cracks and tears are encountered. Thus in parts having undergone larger amounts of deformation prior to bending, larger bending radii should be chosen. In the region between the straight lines G1 and G2, both surface roughening and cracks start to appear. Successful bending operations can be performed below line G2



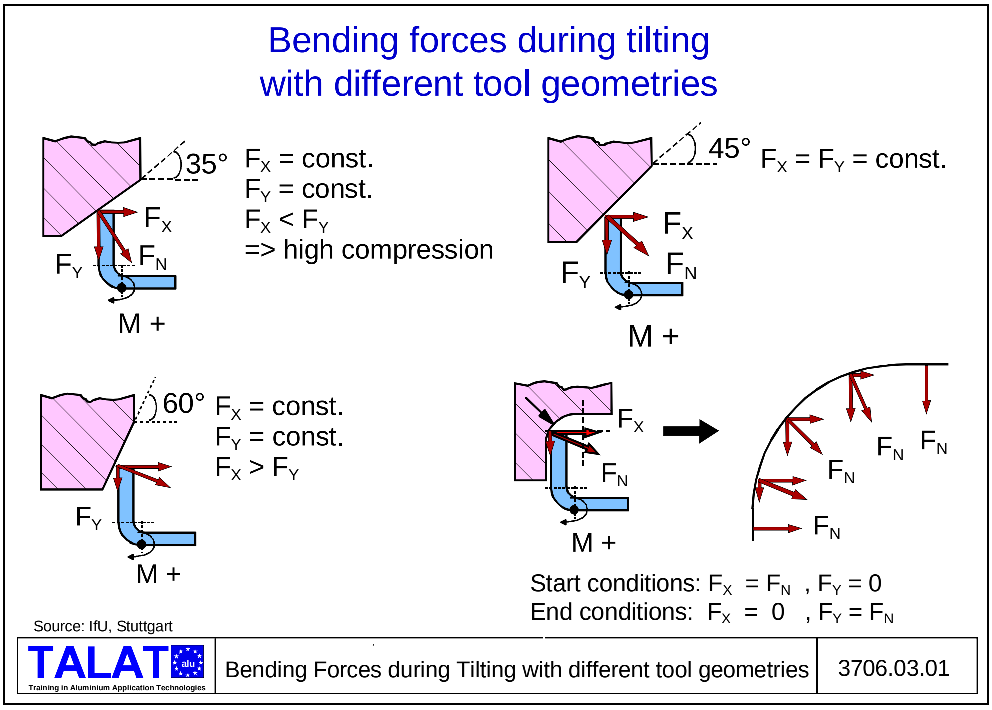
Tearing Behaviour as a Function of Prestraining 3706.02.09

3706.03 Pre-Folding Operation

Bending Forces with Pre-Bending Punches Having Different Surface Forms

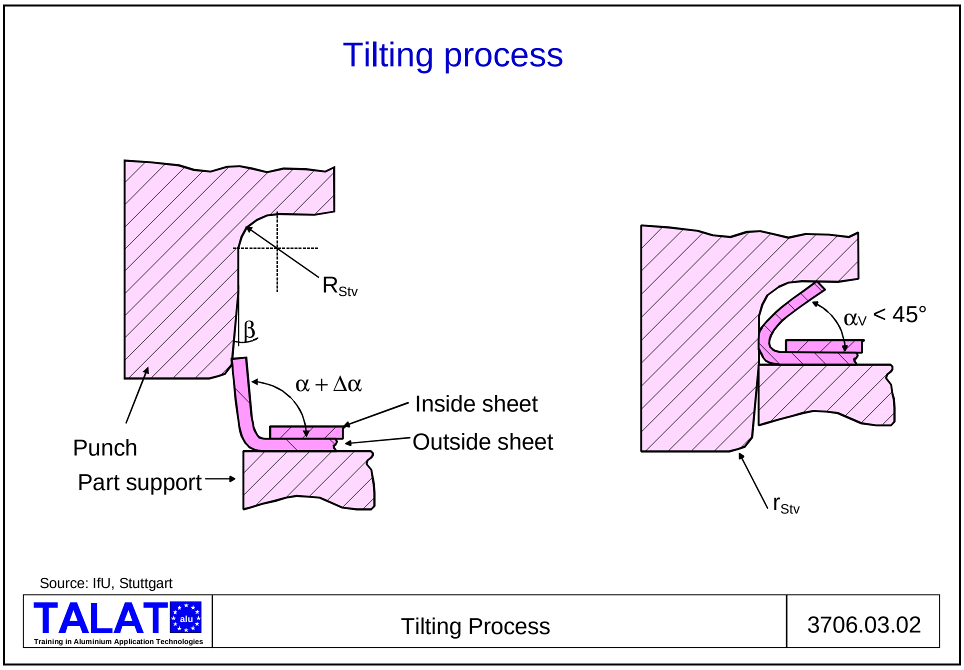
During prefolding (bending from 90° to 135°), an effort is made to maintain a constant radius required for the first bending operation, as explained earlier. The prefolding with tools having a 45° angle is common for steel sheets but has been found to be unsuitable for aluminium sheets, since the bending strain will concentrate at the zone of the initial radius of the down-flange causing this radius to decrease. A solution is illustrated in the lower part of **Figure 3706.03.01.**

Figure 3706.03.01 shows the forces acting when different tool angles are used and also for tools with a curved working surface. It is clear from the figure that a large vertical force component F_y acting at the beginning of the folding operation causes a compression and a back-bending moment. Therefore, folding should be started with as high a horizontal force component F_x as possible. As bending proceeds, the horizontal force component should decrease, with the vertical force component increasing at the same time. This procedure can be achieved with a suitable design of the pre-folding tool.



Pre-Folding Process for Aluminium

The pre-folding of aluminium sheets should preferably be carried out using punches with a curved surface, **Figure 3706.03.02**, so that the bent sheet part can be rounded as in the bordering operation. In order to compensate for the springback, the punch is constructed with an entry angle of β. The angle α_V should be 2° to 4°smaller than 45° so that when the stress on the bending part is removed, an angle of $\alpha_V + \Delta\alpha_V$, which is smaller than or equal to 45°, is obtained.

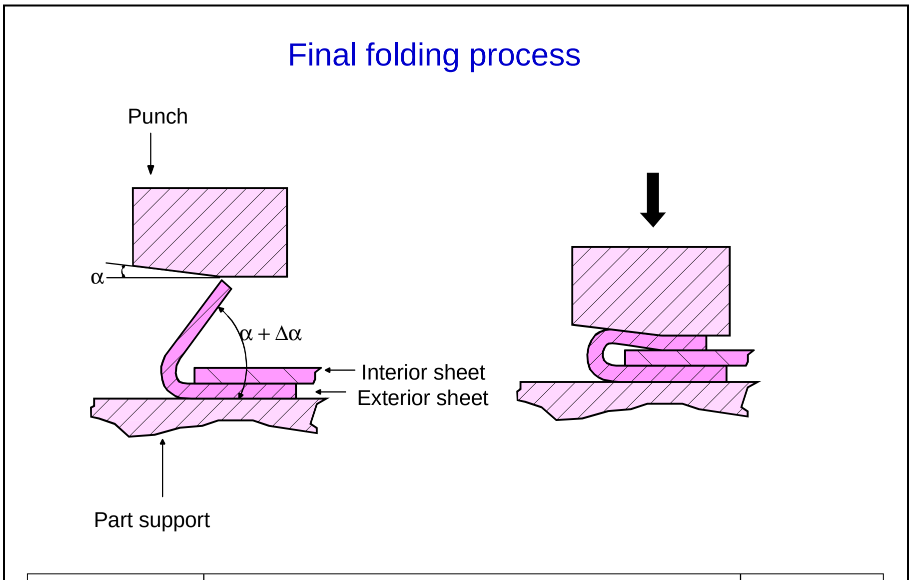


3706.04 Final Folding Operation

Final Folding Process

If the minimum radius set during 90° down-flanging and during pre-folding to 135° is successfully maintained, then crack-free folds can be obtained in most cases even during the final folding to 180°.

In order to maintain the bead (rope hem) radius during the final folding operation, the punch can be designed with an inclined surface with an angle α to the horizontal which can be varied, depending on the sheet thickness and the minimum allowable inside bending radius, **Figure 3706.04.01.**



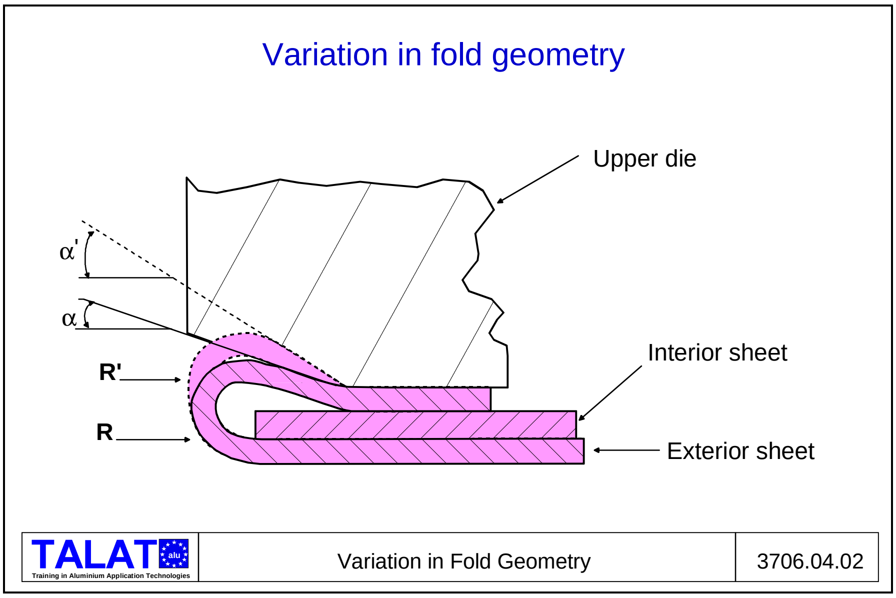
Final folding process 3706.04.01

In order to ensure that the fold edge, which in most cases is also a visible surface, is free of surface markings, the final folding operation has to be conducted without any contact between the tool and the folded edge. Experiments were conducted with an adjustable stopper for positioning the parts to be folded. The stopper is designed to permit movement during the forming operation. Experiments with a rigid, motion-free stopper have shown that during folding along a convex line, the folding edge is heavily compressed.

The contour line of the inside sheet or the inside part must correspond to the bending line geometry of the outside part.

Variations in Fold Geometry

In order to adjust the final folding tool to conform to the geometrical requirements given by the sheet thickness and the smallest possible bending radius, the angle α of the folding punch can be varied to suit the final geometry of the fold, see **Figure 3706.04.02**.



Final Geometry of Fold

The final geometry of the fold is usually defined as a function of the sheet thickness s_a of the outer sheet metal part. The minimum radii which can be obtained during folding are important points to consider, see **Figure 3706.04.03**.

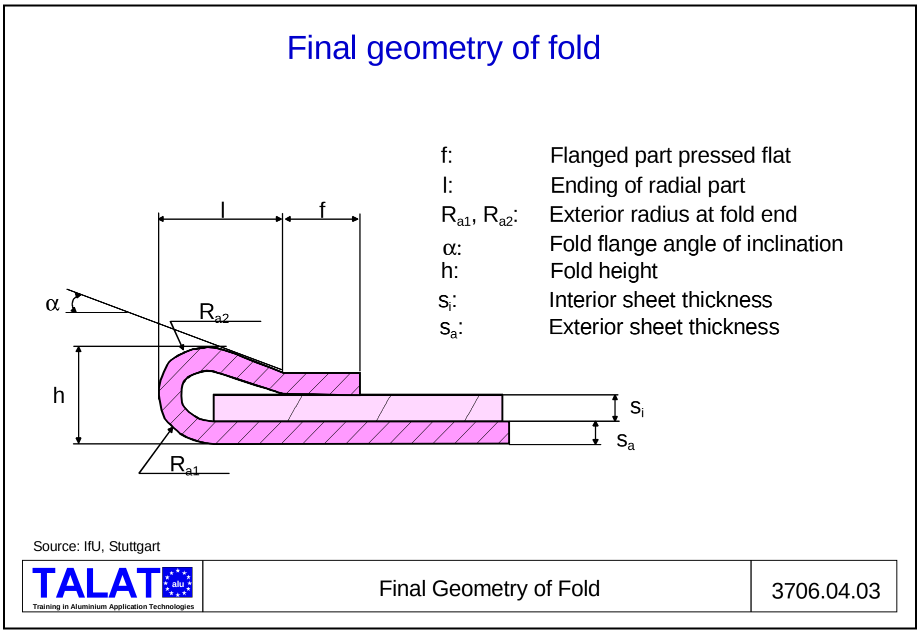


Figure 3706.04.03 illustrates that the outside radii of the fold edge (R_{a1}, R_{a2}) of a bead fold can be varied. These radii depend on the inside bending radius r_i used for the 90° bending as well as on the geometry or angle α of the final folding punch.

3706.05 Literature/References

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3706.06 List of Figures