TALAT Lecture 3704

Deep Drawing

15 pages, 16 figures

Advanced Level

prepared by
K. Siegert and S. Wagner, Institut für Umformtechnik, Universität Stuttgart

Objectives:

- Definition and explanation of terms
- Teaching the most important fundamental laws governing deep drawing
- Special considerations for deep drawing of aluminium sheet metal

Prerequisites:

- General background in production engineering
- TALAT Lecture 3701

Date of Issue: 1994

3704 Deep Drawing

Table of Contents

3704.01 Definitions and Fundamentals of the Deep Drawing Process

Definition of Deep Drawing

Deep drawing is one of the most important processes for forming sheets metal parts. It is used widely for mass production of hollow shapes in the packing industry, automotive industry etc.. According to the definition in DIN 8584, deep drawing is the tensile-compressive forming of a sheet blank (or, depending on the material, also of foils or plates) to a hollow body open on one side or the forming of a pre-drawn hollow shape into another with a smaller cross-section without an intentional change in the sheet thickness, see **Figure 3704.01.01**. The process limitations are laid out by the conditions required to transmit the force into the forming zone. The drawing force necessary for the forming is transmitted from the punch to the work-piece base and from there to the forming zone in the flange. The resulting limiting deformation in the force application zone has nothing to do with the depletion of the forming capacity of the material in the forming zone. The process limits are reached when the largest applied drawing force cannot be transmitted to the forming zone in the flange. From this condition, one can derive the characteristic behaviour of deep drawing, that a number of forming steps can be carried out consecutively without an intermediate annealing step. Subdividing the whole process into a number of drawing steps has the advantage that the tensile force acting at the force application zone can be reduced. Most special processes which have been developed, make use of this fact [1].

Definition of Deep Drawing

Definition: (DIN 8584) Deep drawing is defined as a tensile-compressive sheet forming process in which a plane blank is formed into a hollow part open on one side or an open hollow part is formed into another hollow part with a smaller cross-section.

"Deep drawing in a single draw" or **"deep drawing in one step"** is the forming of a plane sheet section (blank) into an open hollow shape.

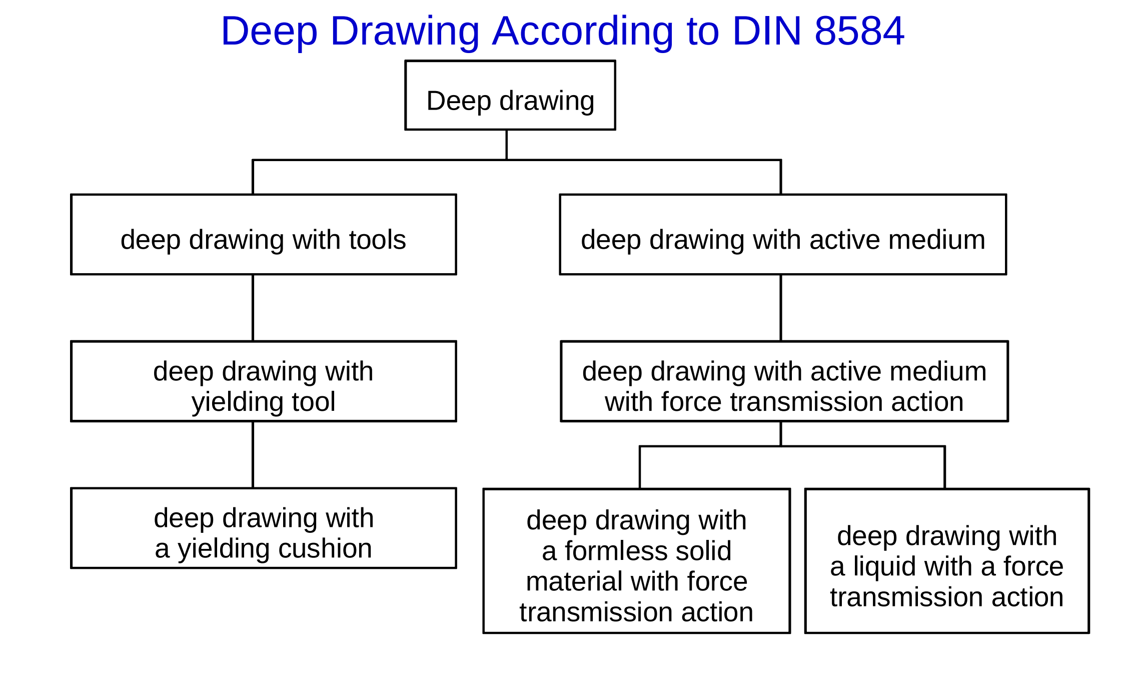
"Redrawing", is the forming of an open hollow shape into one with a smaller cross-section.

Source: IfU Stuttgart

TALAT alu – Training in Aluminium Application Technologies	Definition of Deep Drawing	3704.01.01

Classification of the Deep Drawing Process

According to DIN 8584 deep drawing processes are classified as outlined in **Figure 3704.01.02**



TALAT Training in Aluminium Application Technologies | Classification of the Deep Drawing Process According to DIN 8584 | 3704.01.02

Based on the type of force application, the deep drawing processes can be divided into three methods:

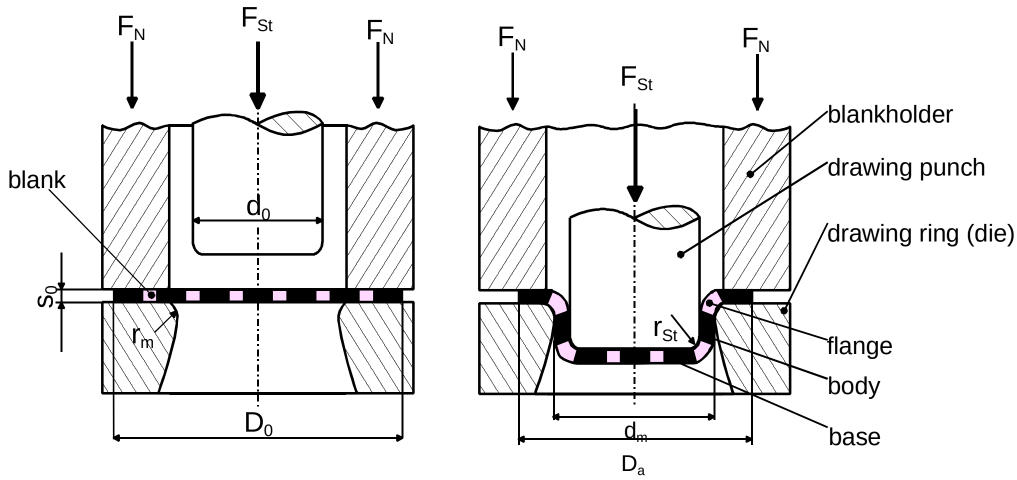
1) deep drawing with tools
2) deep drawing with an active medium
3) deep drawing with active energy

Generally, only the first two methods are used, deep drawing with active energy being of no practical importance [1].

Deep Drawing with a Blankholder

The general terms and definitions of deep drawing with a blankholder are illustrated in **Figure 3704.01.03.** The deformation in the flange is a result of tangential compressive stresses and radial tensile stresses, when the sheet blank with diameter D_o is drawn through the die to a cup with the punch diameter d_o. The blankholder force F_N prevents the formation of folds. The stress due to the blankholder pressure is small compared to the radial and tangential stresses.

Deep Drawing with Blankholder

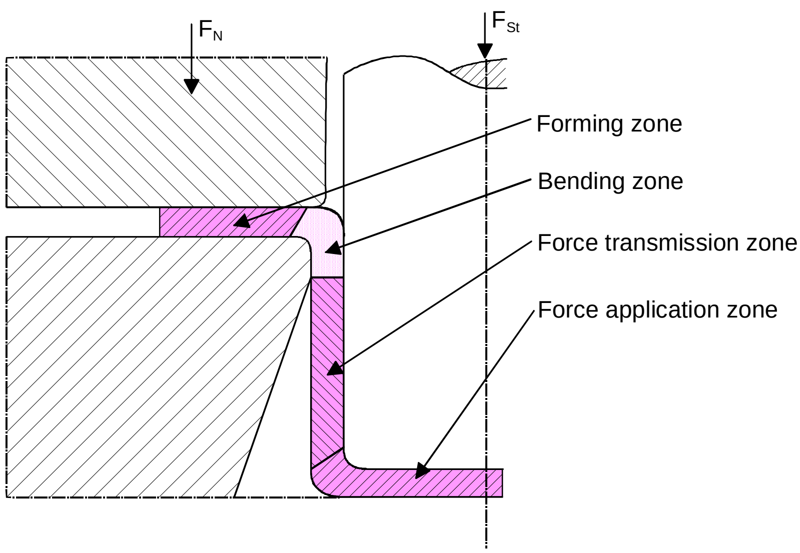


Starting diameter of blank	D_0	Punch edge radius	r_{St}
Punch diameter	d_0	Die diameter	d_m
Sheet thickness of blank	s_0	Die radius	r_m
Punch force	F_{St}	Drawing gap	U_z
Blankholder force	F_N	Momentary flange diameter	D_a

Source: IFU Stuttgart

TALAT Training in Aluminium Application Technologies	Deep Drawing with Blankholder	3704.01.03

Stress Zones During Deep Drawing



Source: IfU Stuttgart

TALAT Training in Aluminium Application Technologies	Stress Zones During Deep Drawing	3704.01.04

Stress Zones during Deep Drawing

During the drawing process the cup can be divided into four characteristic zones, **see Figure 3704.01.04,** with different state of stress and deformation:

– The blankholder force F_N prevents folds of „type 1“.

– The forming zone is the sheet material between the flange outer edge (D = f(h)) and the outlet of the material to be formed from the drawing ring radius („die shoulder“)

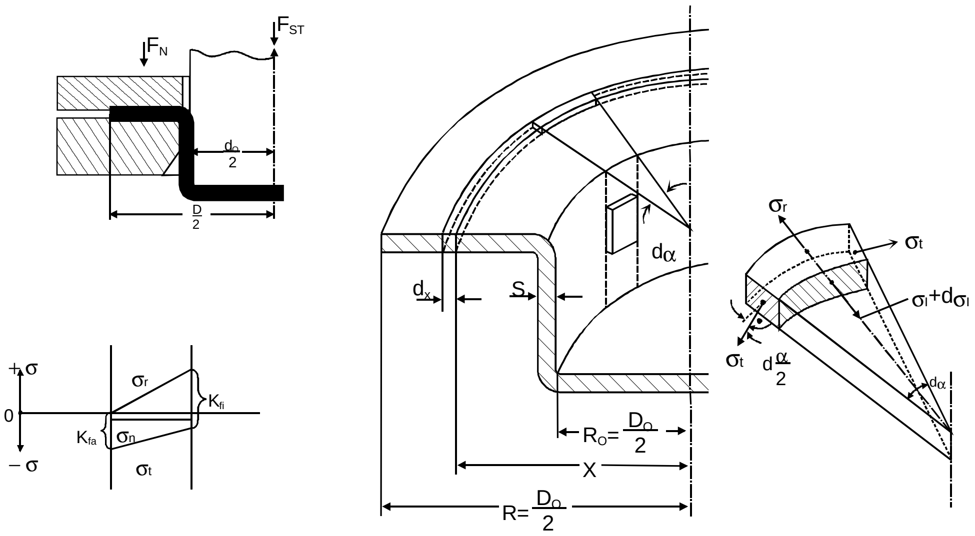
– The surface area of the drawn part is about the same as that of the starting blank. Consequently, the sheet thickness remains almost constant.

– The base of the drawn part is formed on the same principles that apply to mechanical drawing.

Stresses Acting during Deep Drawing

During the deep drawing of cylindrical cups, the parts of the blank under the blankholder are subjected to a radial tensile stress and a tangential compressive stress, see **Figure 3704.01.05**. A minimum normal stress must be applied in order to prevent buckling of the sheet (folds of „type 1“). This normal stress, however, also affects the friction between the blankholder and sheet as well as between sheet and drawing ring. Generally, a higher normal stress, i.e., a higher blankholder force, leads to higher frictional forces [2].

Stresses Acting in the Forming Zone
During Deep Drawing with Blankholder

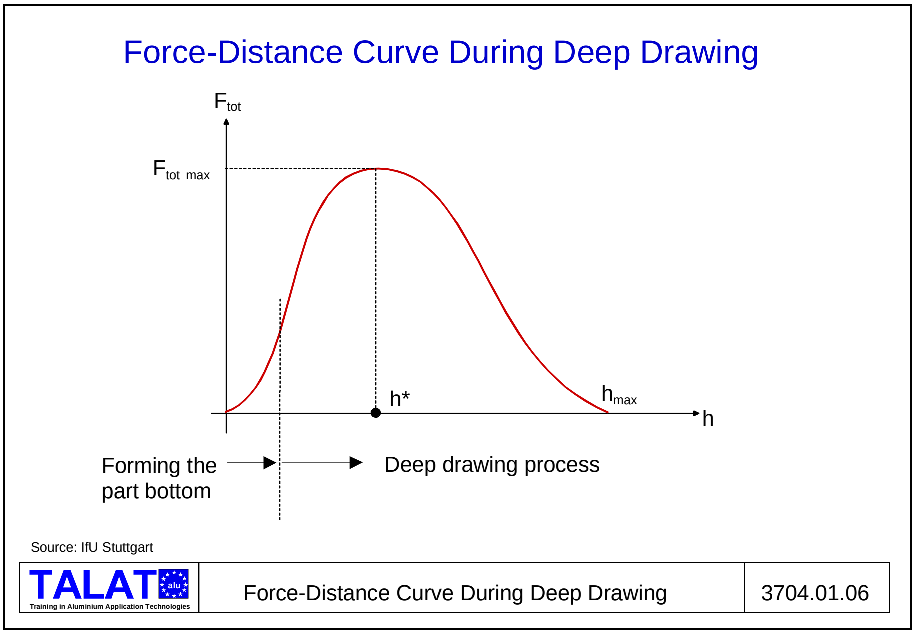


Source: IfU Stuttgart

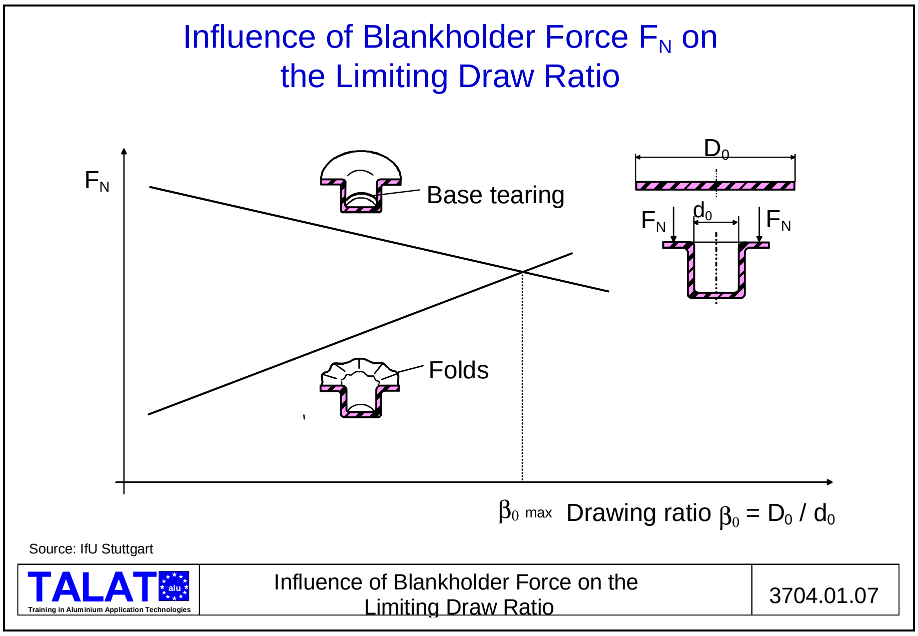
TALAT Training in Aluminium Application Technologies	Stresses Acting During Deep Drawing	3704.01.05

Force-Displacement Curve during Deep Drawing

During the deep drawing process, the drawing force increases from zero up to a maximum value and then falls down again to zero, see **Figure 3704.01.06**. The base is first formed in a manner similar to the stretch forming process and then the actual drawing process follows.



Force-Distance Curve During Deep Drawing 3704.01.06



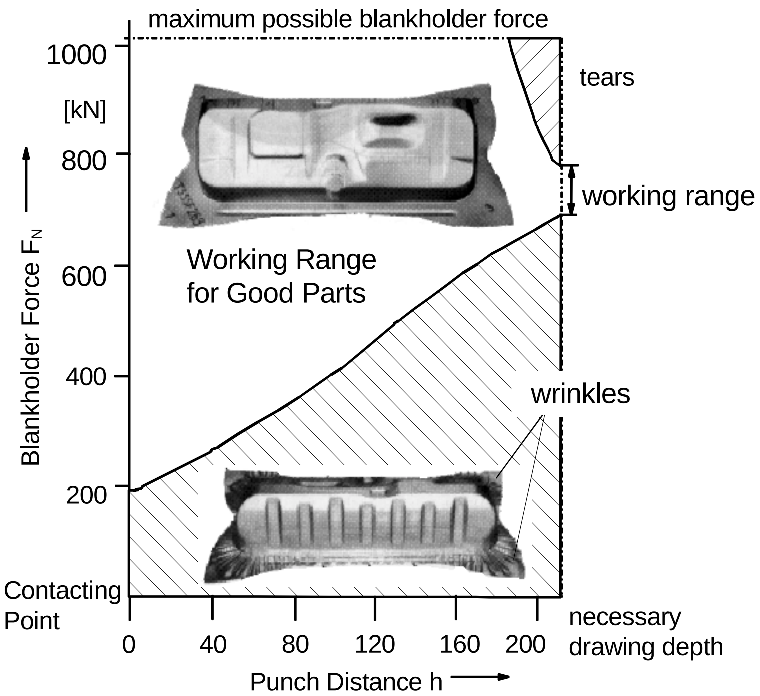
Influence of Blankholder Force on the Limiting Draw Ratio 3704.01.07

Influence of Blankholder Force on the Limiting Draw Ratio

As illustrated in **Figure 3704.01.07** the process limits depend on the properties of the sheet material, on the lubricant, on the tool geometry and the forming parameters. The upper process limit is determined by the formation of tears. The lower limit is determined by the tendency to build folds. These two failure criteria then determine the limits of the process. The limiting draw ratio $ß_{omax}$ is a measure of the process limit due to tearing. The limiting draw ratio can be increased by minimising the punch force and by increasing the tearing factor. Calculations and experiments have shown that during deep drawing, the ratio d_o/s_o has an influence on the limiting draw ratio. The limiting draw ratio decreases with increasing ratio d_o/s_o. The higher the coefficient of friction under the blankholder, the larger is the decrease of $ß_{omax}$ with an increasing d_o/s_o ratio [2].

Working Range for Deep Drawing

Figure 3704.01.08 illustrates the limits of the blankholder force for a fuel tank shell; an upper limit due to the formation of tears and a lower limit due to the formation of folds of „type 1“. The working range for faultless parts lies between these limits. The upper limit is also determined by the maximum blankholder force which can be delivered by the pressing machine [3].

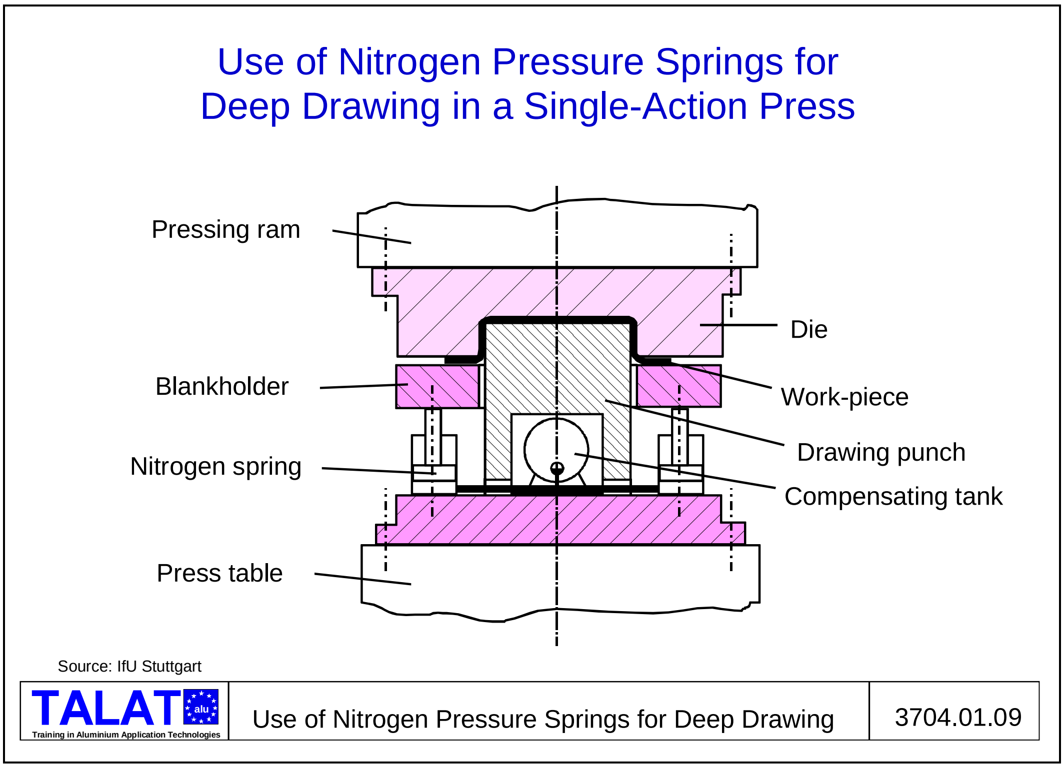


Source: IfU Stuttgart

TALAT Training in Aluminium Application Technologies	Working Range for Deep Drawing	3704.01.08

Use of Nitrogen Pressure Springs for Deep Drawing

In drawing aluminium carbody parts it is important to control the drawing parameters carefully over the whole drawing operation. For this purpose the use of nitrogen pressure springs in the press is advantageous. **Figure 3704.01.09** shows a simply acting press for deep drawing. The blankholder force is applied through the action of nitrogen springs integrated in the machine. These gas pressure springs have the advantage that the applied force is almost constant over the whole spring movement [4].



Optimized Design of Deep Drawing Machines for Aluminium

In forming of steel sheets the useful deformation capacity is extended well beyond the uniform elongation into the range of fracture elongation (necking). When forming aluminium sheet metal parts deformation should be confined to the region of uniform elongation and the region of necking should be avoided. For aluminium alloys it is important to work with prototype tools to determine the feasibility of drawing as well as the springback effect. In addition, it is helpful to ascertain the tolerances which can be attained by altering the tools. Some general recommendations should be remembered when designing press tools for the successful drawing of aluminium parts, see **Figure 3704.01.10**. Special attention should be given to the subject of lubrication. The aluminium industry offers aluminium sheets with a wide range of surface morphologies, including sheet surfaces with spark eroded textures (EDT) which allow a good distribution of lubricant, thus making it possible to obtain better performances with acceptable surfaces for difficult forming operations [Ref. 5 and TALAT Lecture 3702].

Aluminium Optimised Construction of Deep Drawing Machines

- Drawing punch radius used should be twice as large as that for steel, if possible
- Choose low drawing depths
- Avoid vertical body walls
- Draw tapers of 30 degrees or more on the long sides
- Relieving cuts lead to tears
- Smaller bending radii should be chosen for bending in a direction perpendicular to the rolling direction

Source: HFF Report no.12, 1993

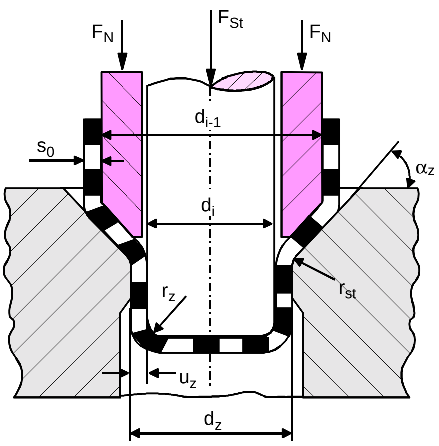
TALAT	Aluminium Optimised Construction of Deep Drawing Machines	3704.01.10

3704.02 Re-Drawing Processes for Increased Drawing Depths

Direct Re-Drawing

To obtain larger drawing ratios direct re-drawing is necessary. The principle scheme is shown in **Figure 3704.02.01.** The trace of stresses in the forming zone is qualitatively the same as in the first draw. Contrary to the first draw, however, the conical shape of the drawing ring makes it possible to apply a normal force to the sheet even without a blankholder. This normal force then presses the work-piece against the drawing ring.

Tool Form for Redrawing



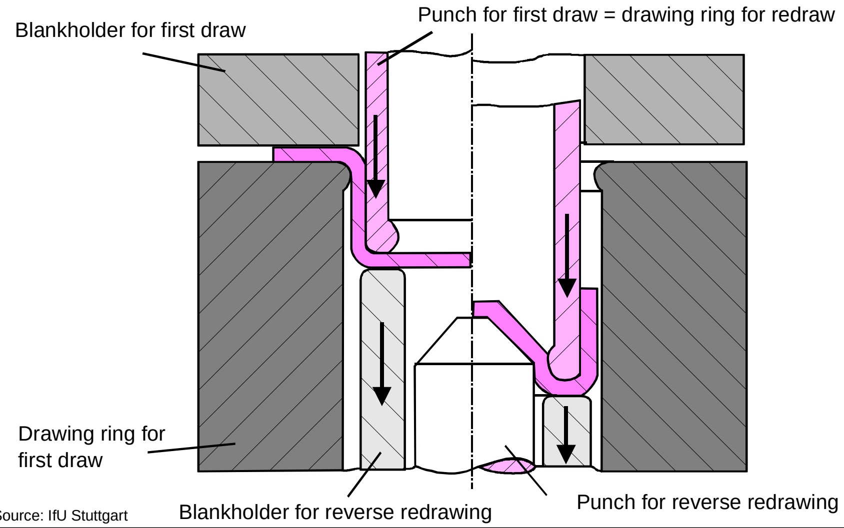
Source: IfU Stuttgart

TALAT	Direct Redrawing	3704.02.01

Reverse Re-Drawing

During reverse re-drawing, the first draw is combined with an additional drawing step, whereby the reverse re-drawing punch works opposite to the working direction of the first draw punch. One has to differentiate between reverse re-drawing without a ring and the tool oriented reverse re-drawing (see **Figure 3704.02.02**). A main advantage of reverse re-drawing over conventional direct re-drawing is the reduced amount of bending over the die curvature. Normally, both first draw and reverse re-drawing are carried out together in one working step. The combination of both draws means that one operational step can be eliminated. In the case of a stepped tool one transport stroke is also eliminated. For this forming process, however, a larger punch stroke or, depending on the tool construction, even a triple acting press may be required.

Reverse Redrawing



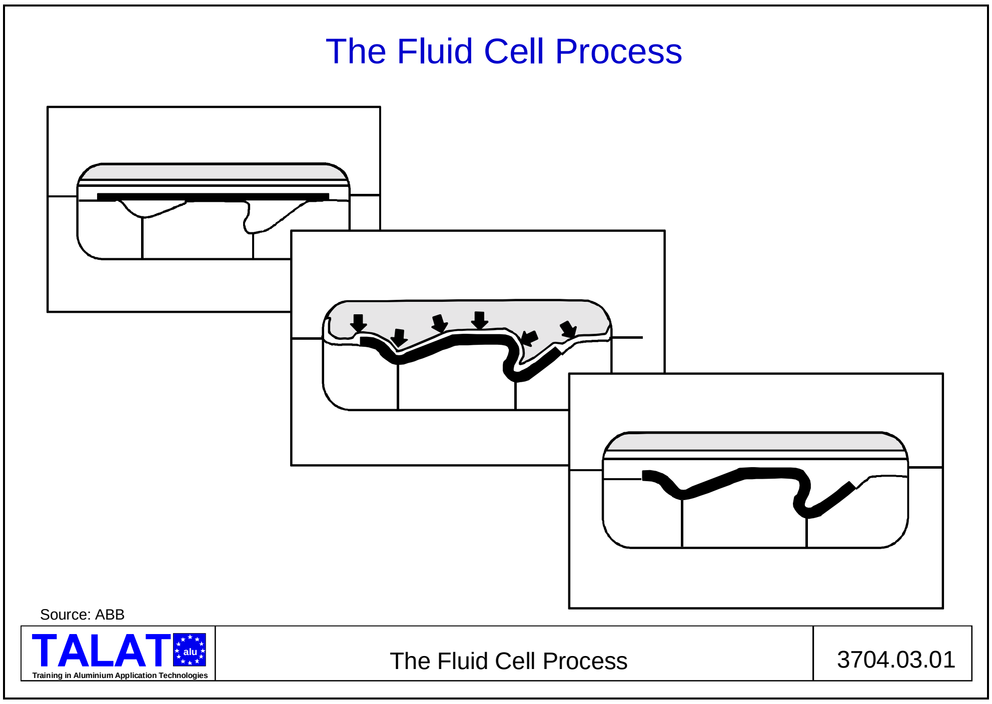
Source: IfU Stuttgart

TALAT	Reverse Redrawing	3704.02.02

3704.03 The Fluid Cell Process

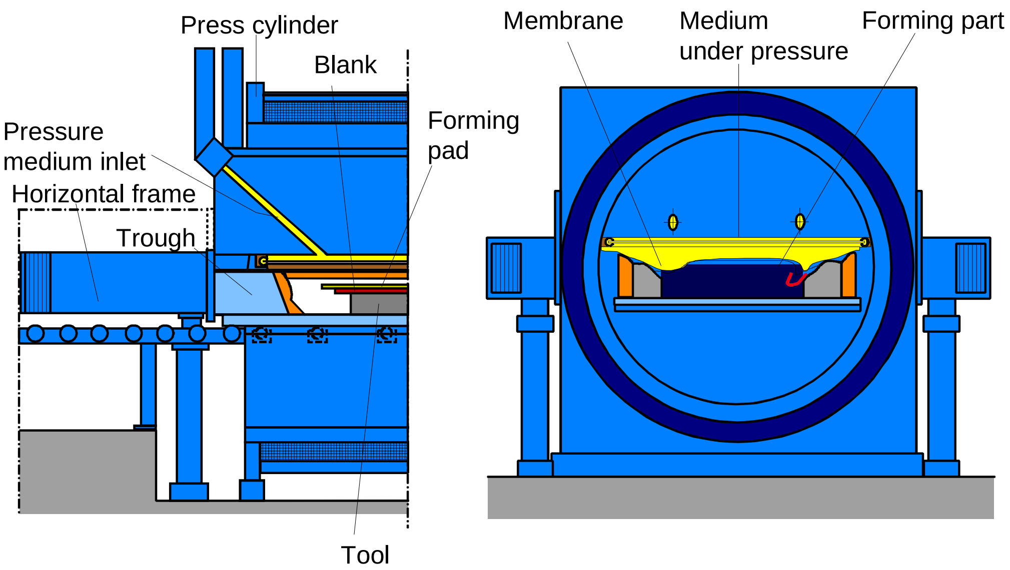
General Working Principle

As opposed to the hydromechanical drawing process without a membrane, the fluid cell process works with a polyurethane membrane. The rigid drawing die is replaced by a "hydraulic cushion" closed on all sides, see **Figure 3704.03.01**. The top side which presses against the forming die, consists of the membrane. During the working stroke of the punch the force is transmitted through the active medium onto the membrane and finally through the membrane to the blank, pressing it both against the punch as well as against the blankholder. This eliminates the formation of folds of „type 1“ and frictional forces can act between punch and the drawing part. Thus frictional forces can be transmitted between punch and workpiece, thereby displacing the normal failure zone from the exit of the punch bottom radius further onto the rib of the drawn part, i.e. to a location with a higher flow stress. The limiting draw ratio as well as the form and dimensional precision which can be obtained depend on the control of pressure in the active medium.



Schematic View of a Fluid Cell Press

The fluid cell drawing process has been applied especially in the aircraft industry for producing components with relatively small drawing depths. Another interesting application, in use during the last few years, is the fabrication of prototypes in the automobile industry. **Figure 3704.03.02** shows a machine with equipment and work-piece removal station as well as a sectional view illustrating the drawing process. The forming movement of the tool of conventional presses is replaced by the supply of pressurised oil from an external hydraulic aggregate. Using extremely high forming pressures, it is even possible to form materials which are otherwise difficult to form.



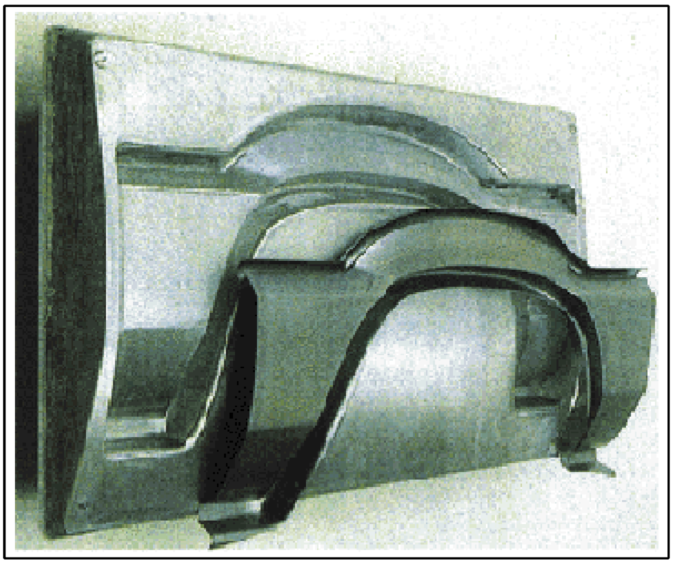
Source: ABB

TALAT Training in Aluminium Application Technologies	Schematic View Showing the Principle of a Fluid Cell Press	3704.03.02

A Wheel-House Fabricated by the Fluid Cell Process

Figure 3704.03.03 shows the rear wheel-house of a caravan fabricated in a single drawing operation with a 1,000 bar forming pressure. It is noteworthy that the forming die was a NC-milled aluminium tool.

A Wheel-house fabricated by the Fluid Cell Process

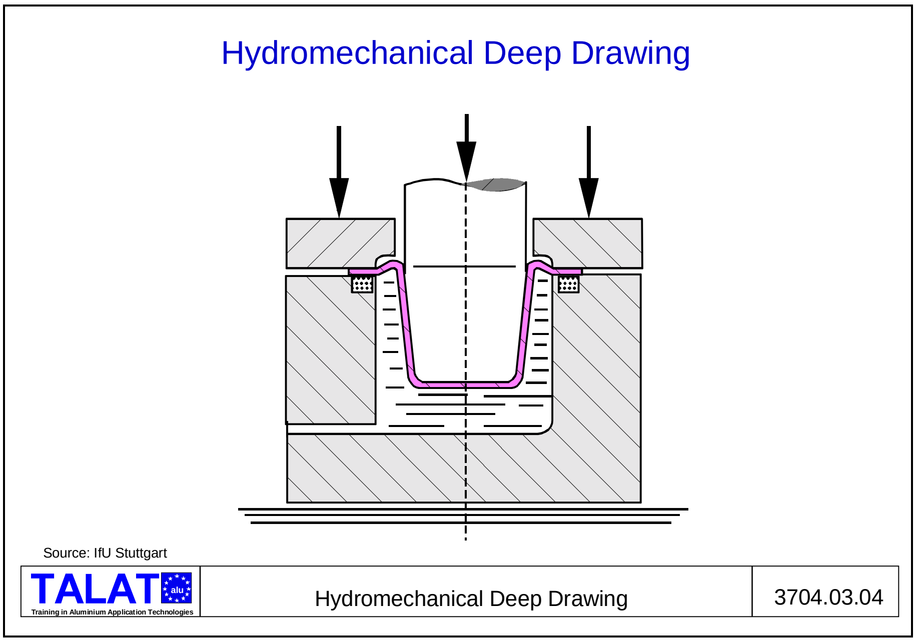


Source: ABB

TALAT Training in Aluminium Application Technologies	A Wheel-house Fabricated by the Fluid Cell Process	3704.03.03

Hydromechanical Deep Drawing

Another sheet metal drawing process which has particular merits for forming aluminium is the hydromechanical deep drawing process. As opposed to conventional deep drawing with rigid tools, the work-piece is pressed into a bottom tool filled with liquid, instead of a rigid die. The principle is explained in **Figure 3704.03.04**.



With hydromechanical deep drawing it is possible to form flat sheet blanks or preformed sheets to hollow bodies of various complex geometries. With this process it is also possible to produce shapes with tapered bodies in a single step, which would otherwise require several drawing steps in a conventional deep drawing process. Further advantages are: better form and dimensional precision, a higher drawing ratio, reduced residual stresses and the production of parts with undamaged surfaces.

3704.04 Literature/References

[1] DIN standard 8584: Fabricating process tensile-compressive forming.

[2] **Lange, K.**: Umformtechnik, Vol. 3, Springer Verlag Berlin, Heidelberg, New York.

[3] **Klamser, M.**: Hydraulische Vielpunkt-Zieheinrichtung im Pressentisch einfachwirkender Pressen. In Siegert, K. (ed.): Zieheinrichtungen einfachwirkender Pressen für die Blechumformung. Oberursel: DGM-Informationsgesellschaft, 1991

[4] **Schlegel, M.**: Gas als Feder. Fertigung, Landsberg, October 1992, p. 44-51.

[5] **Haas, E.**: Verarbeitungstechniken von Aluminiumwerkstoffen. HFF-Bericht No. 12. Umformtechnisches Kolloquium, Hannover, March 1993.

3704.05 List of Figures