

TALAT Lecture 3502

Impact Extrusion Processes

26 pages, 35 figures

Advanced Level

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Objectives:

- To describe the impact extrusion processes as well as the forces and deformations acting on the tools and work-piece in order to give insight into the relation between part design, process and tooling

Prerequisites:

- Basic knowledge about the formability of metals
- Background in mechanical engineering

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3502 Impact Extrusion Processes

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3502.01 Definitions and Classifications

The forming process impact extrusion is defined in DIN 8583, part 6, as follows (**Figure 3502.01.01**):

Impact extrusion is the pressing out of a work-piece (e.g. rod section, sheet sections) placed between tool parts, through an orifice with the help of a punch. It is used mainly to produce single components.

Impact extrusion is an important bulk forming process and offers a range of special advantages, like:

- optimal usage of material
- high production rates with short piece-production times
- accurate reproduction of dimensions and forms coupled with a good surface quality
- good static and dynamic properties of the components due to the favourable fibre structure and work hardening.

Definition of Impact Extrusion

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Unlike tapering, impact extrusions offer larger degrees of deformation.

Source: DIN 8583, part 6

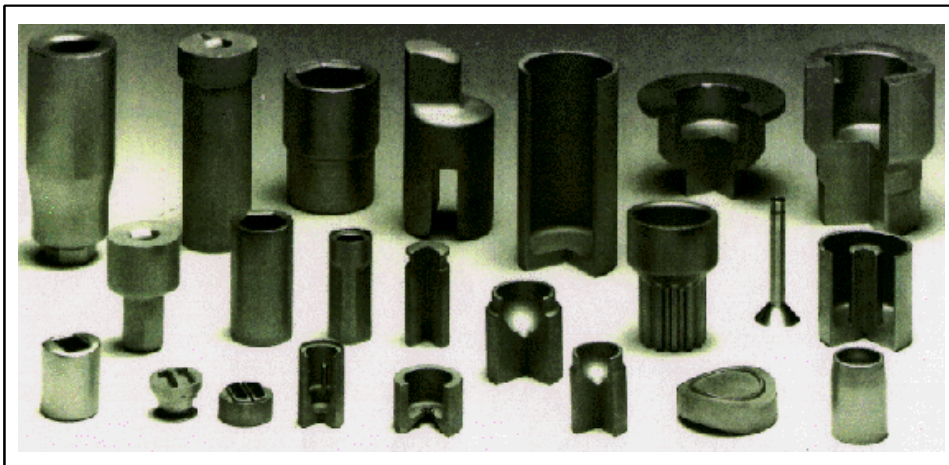


Definition of Impact Extrusion

3502.01.01

Figure 3502.01.02 and **Figure 3502.01.03** show typical impact extruded parts. Impact extrusion is particularly suitable for the fabrication of parts which, with the exception of some additional local machining, are in their near-net-shape condition.

Impact Extruded Parts - I



Impact Extruded Parts - I

3502.01.02

The geometric forms which can be impact extruded are limited mainly to axially symmetrical cross sections, in particular with rotational symmetry. Such parts may contain interior forms which are axially symmetrical or sometimes even unsymmetrical to a limited extent. The required wall thickness is a decisive criteria for the feasibility of fabricating a certain form. Using appropriate tooling techniques and technologies of impact extrusion, it is possible to fabricate components with laterally extending

elements.

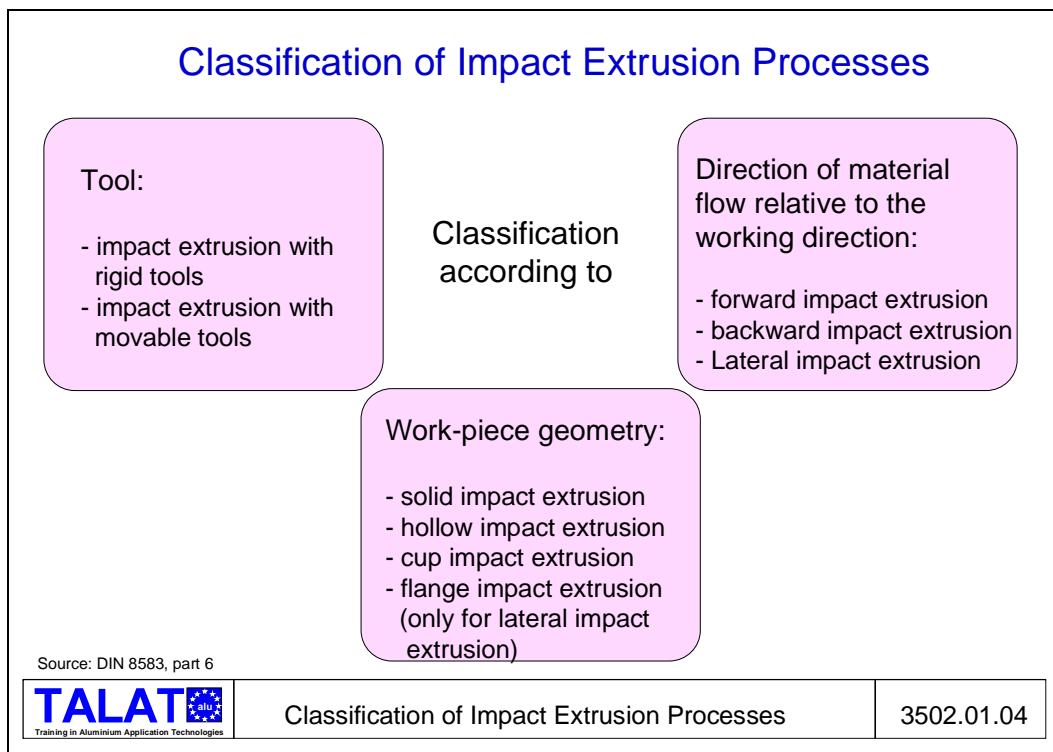
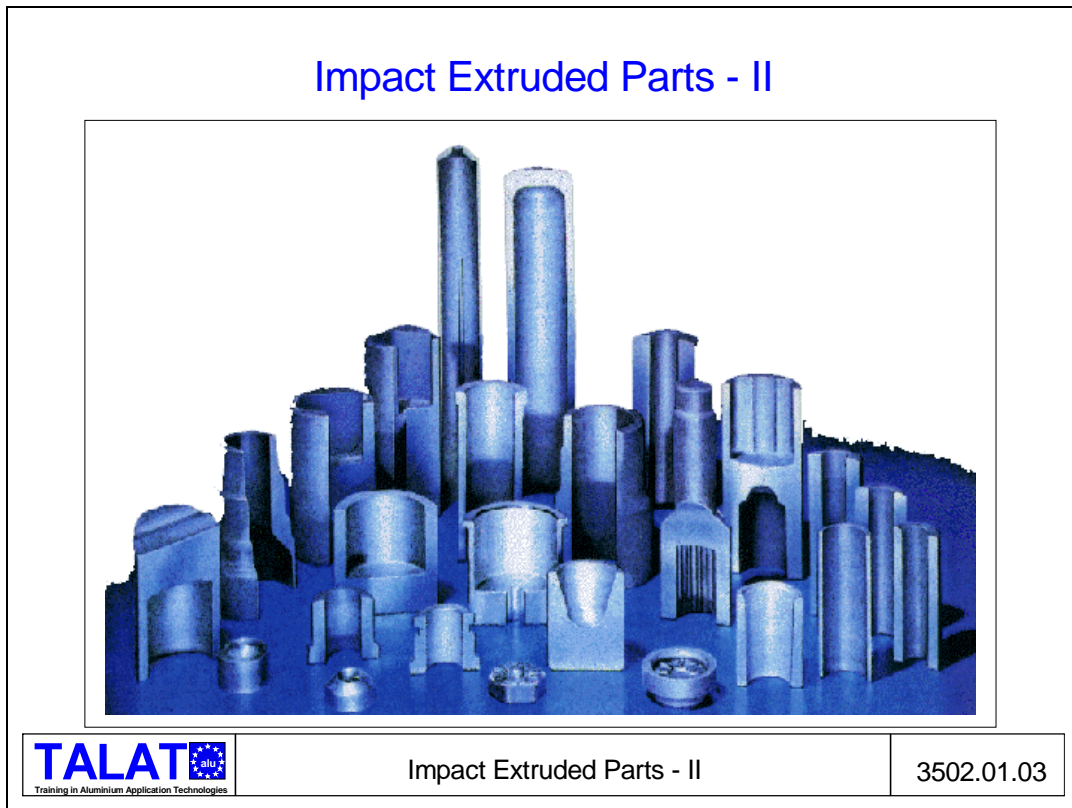


Figure 3502.01.04 shows the classification of impact extrusion processes. According to DIN 8583, impact extrusion, together with tapering and extrusion, belongs to the fabrication processes of „pressing through orifices“ in the main group of „forming by

compressive forces“. The impact extrusion processes can be further sub-divided as follows:

- according to the type of tool in:
impact extrusion with rigid (immovable) tools and impact extrusion with an active medium, which plays a role only for special products;
- according to the direction of material flow relative to the working direction of the machine in:
forwards, reverse and lateral impact extrusion;
- according to the work-piece geometry in:
full, hollow and cup impact extrusion as well as flange impact extrusion (only for lateral impact extrusion);

These basic process variations of impact extrusion are used in combinations among themselves as well as with other bulk forming operations like compressing, upsetting, form pressing, stamping, tapering and drawing. All impact extrusion operations can be conducted at room temperature (cold impact extrusion) as well as by heating to a higher operating temperature, depending on material and process specifications (semi-hot and hot impact extrusion).

3502.02 Fundamentals

Impact extrusion is based on the ability of crystals to glide by slip under certain stresses without destroying the cohesion between the slip planes. In order to be able to cause the crystal structure to form under impact extrusion, the resulting shear stresses or principal stress difference must exceed a certain critical value. This value is generally called the flow stress, k_f .

The change in dimensions of a body during forming is called strain which is referred either to the original dimensions, l_0 , b_0 , h_0 or to the instant dimensions, l_i , b_i or h_i .

For impact extrusion the

conventional or engineering strain :	ϵ_A	=	$\Delta A / A_0$
(reduction in area)	where	ΔA	= $(A_i - A_0)$
and the natural or true strain:	ϕ_A	=	$\ln(A_i/A_0)$
(logarithmic strain)		=	$\ln(1 + \epsilon_A)$

are usually used.

3502.03 Impact Extrusion with Quasi-stationary Material Flow

Process steps

The basic processes „solid forwards, solid backwards“, „hollow forwards and hollow backwards“ all belong to the impact extrusion process with quasi-stationary material flow, which means that on the whole, deformation is distributed homogeneously across the cross-section of the work-piece, a few locally limited exceptions being possible. The forward impact extrusion process is most widely used.

Figure 3502.03.01 illustrates the operational steps during „solid forward“ impact extrusion. The material is first pressed into the holder so that it fills out the cavity. The continued stroke of the punch then causes the material to be pressed out of the die. The deformation and flow zone builds up directly in front of the die opening. In the initial stage of forming the process is non-stationary. With the volume of material leaving the forming zone through the die opening at constant punch speed the process changes to a quasi-stationary forming process. Thus, quasi-stationary states of deformation and deformation speed are created. After completion of the forming operation, the work-piece is removed by a knockout or ejector mechanism.

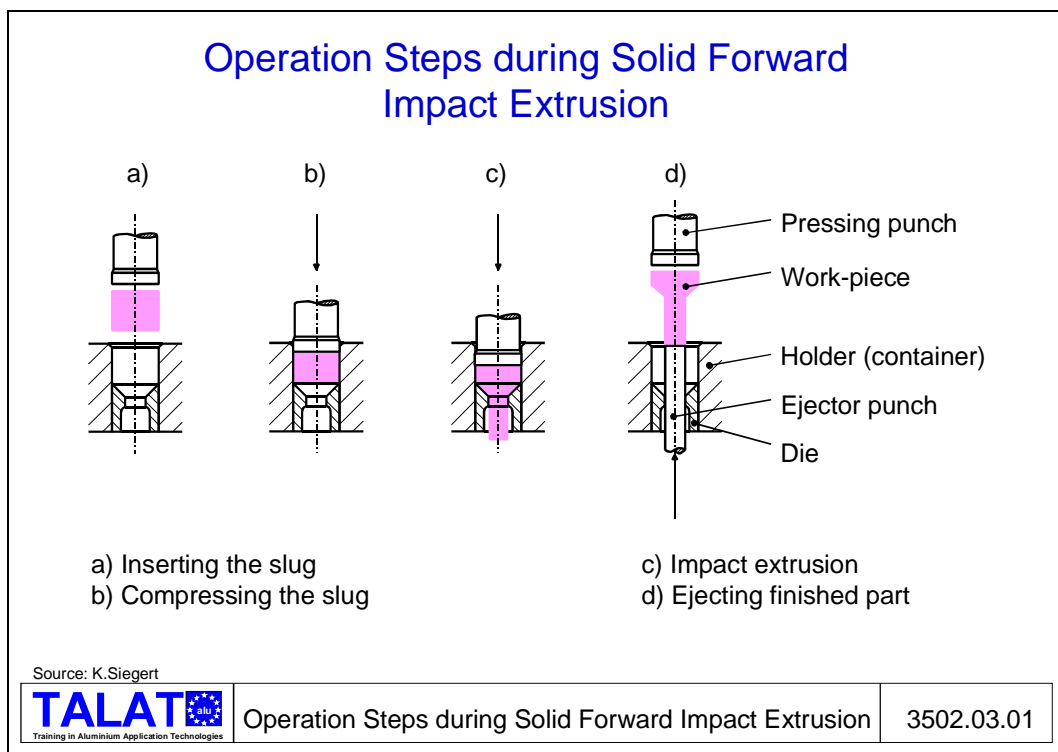


Figure 3502.03.02 illustrates the operation steps during „solid backward“ impact extrusion. During the „solid backward“ extrusion operation, the die and punch build a single unit. The bottom of the holder is closed by an ejector punch. During the forming process, the die moves into the holder. Following the initial compression period, the material is pressed through the die into the hollow punch cavity.

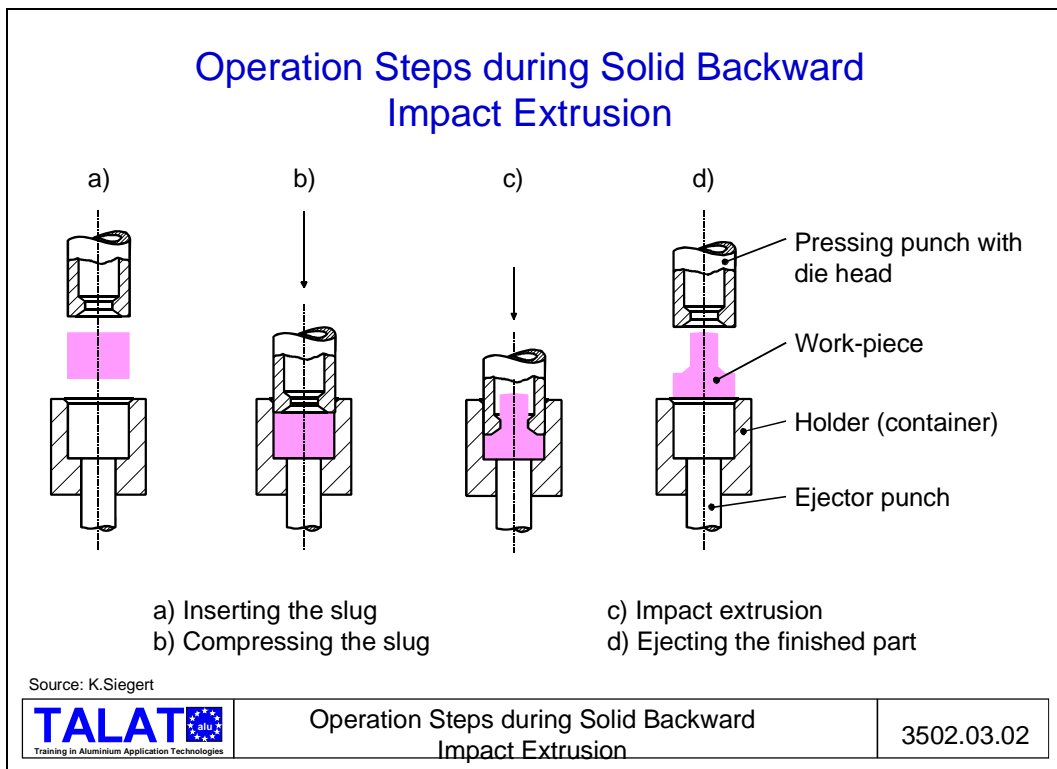
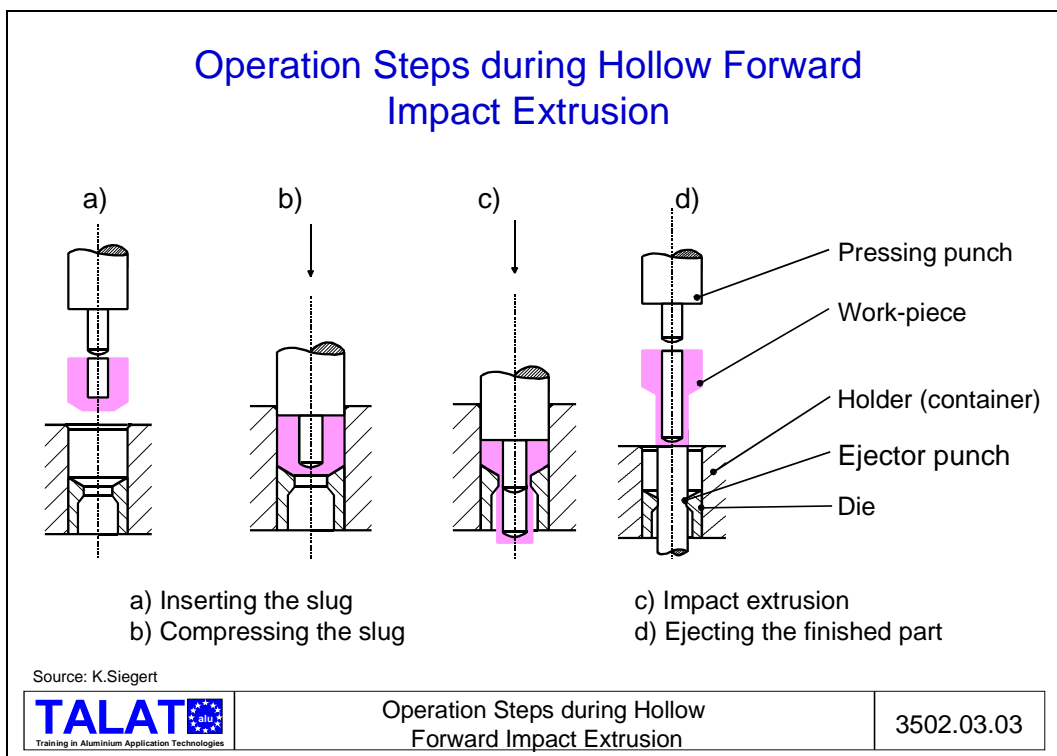


Figure 3502.03.03 shows the operational steps during „hollow forward“ impact extrusion. A shell (or cup) is formed into a shell with reduced wall thickness. The contours of the impact are created by the internal contours of a shaped punch.



There are four different ways to design a punch for hollow impact extrusions which are

shown in **Figure 3502.03.04**, **Figure 3502.03.05** and **Figure 3502.03.06**.

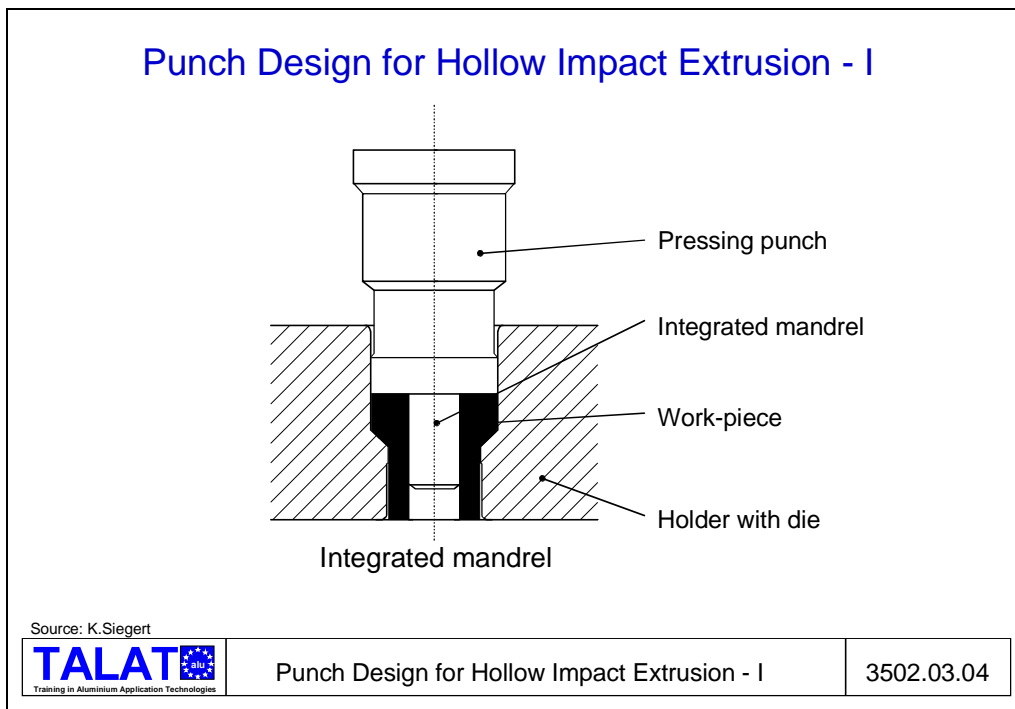


Figure 3502.03.04 illustrates the „integrated mandrel“: The integrated mandrel is the simplest design, but is subjected to unfavourable stresses and notch effects due to the large change in cross-section.

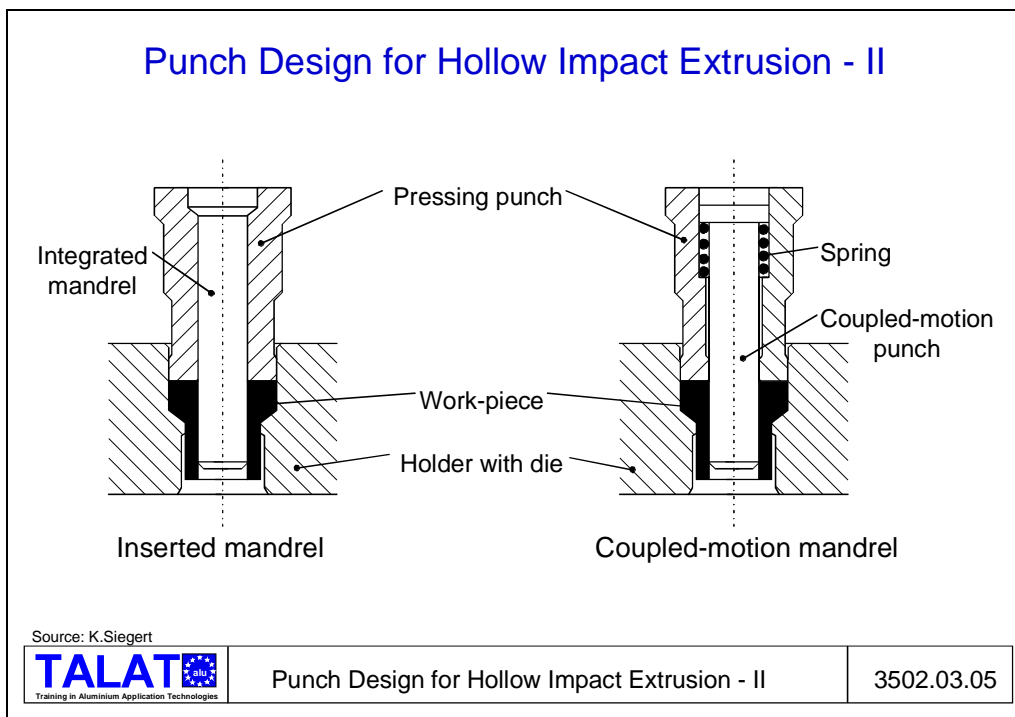


Figure 3502.03.05 shows the „inserted mandrel“ (left). It is a more favourable solution which takes account of the differing operating lives of mandrel and punch. The „moving mandrel“ (right) is supported by a spring in order to reduce the friction between mandrel

and work-piece. The mandrel moves together with the work-piece during forming.

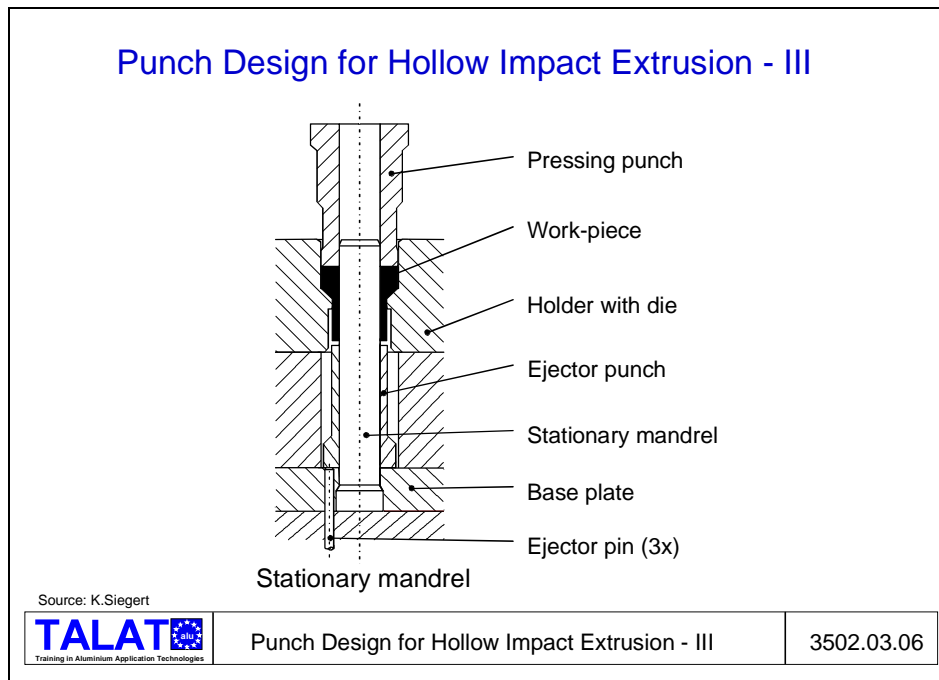


Figure 3502.03.06 shows the „stationary mandrel“: This design has the advantage of a well-guided mandrel, but, at the same time, has more unfavourable friction characteristics.

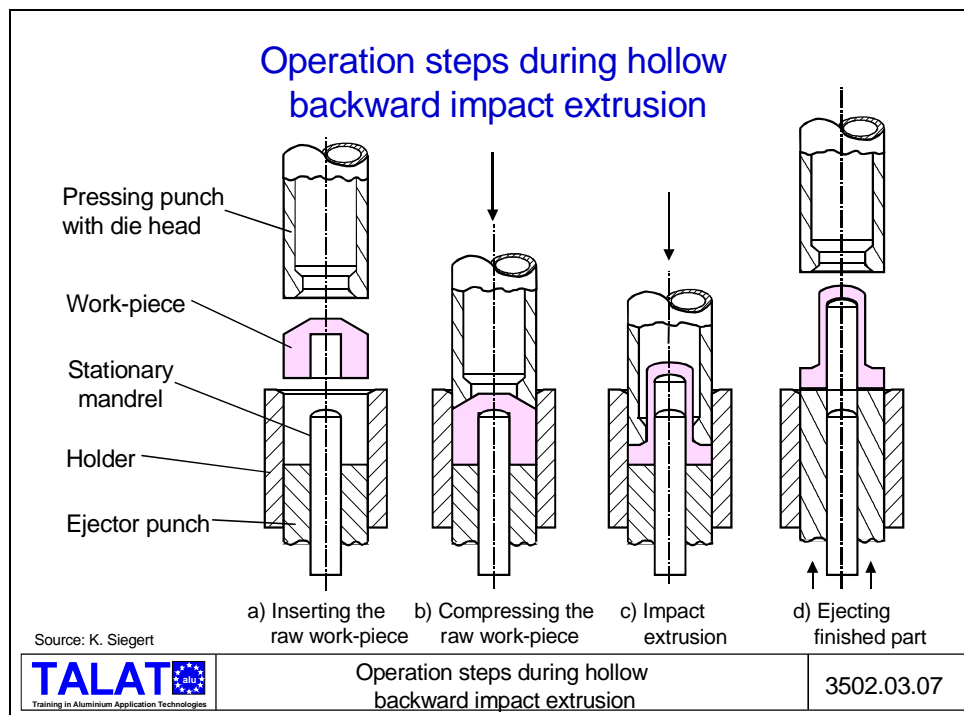
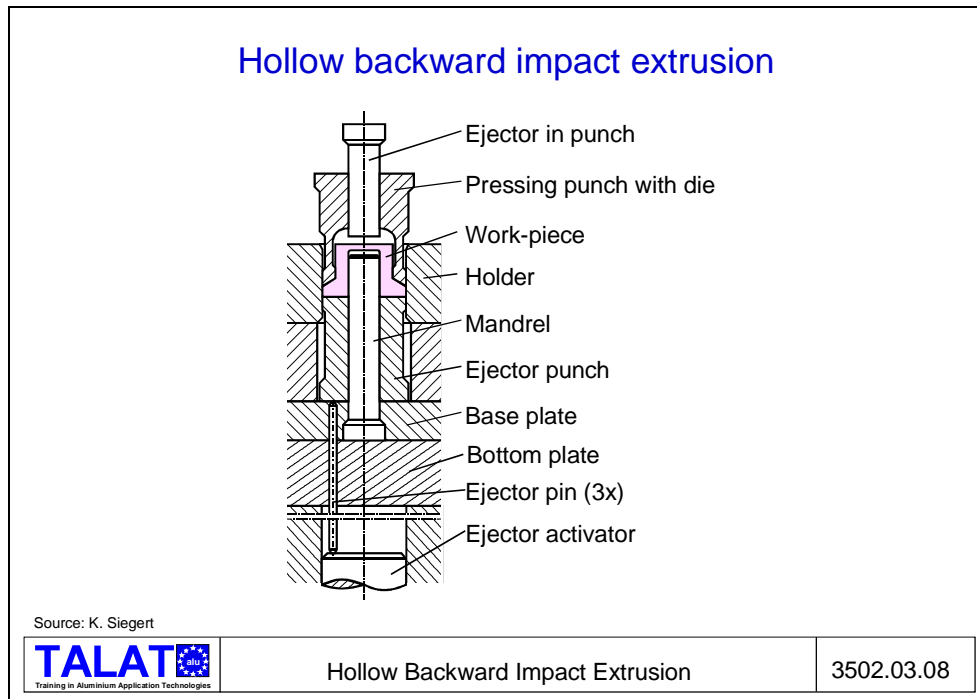


Figure 3502.03.07 illustrates the operational steps during „hollow backward“ impact extrusion. Both „hollow forward“ impact extrusion and „hollow backward“ impact extrusion have, in principle, the same process steps with the exception that in „hollow forward“ extrusion, the contours of the stationary mandrel in the ejector punch are

responsible for the interior contours of the work-piece. In „hollow backward“ impact extrusion the ejector punch tool is fitted with three ejector pins which lift the punch at the end of the operation. The pins are activated hydraulically or mechanically to carry out the ejecting operation, see **Figure 3502.03.08**.



Material Flow and Deformation

Figure 3502.03.09 and **Figure 3502.03.10** show the material flow during „solid forward“ impact extrusion. At the beginning, the forming process is non-stationary till the orifice is completely filled with material. The non-stationary region is indicated by the distorted grid lines. The volume elements of the material are axially compressed and radially expanded. The non-stationary pressing operation causes the material to bulge at the end and to be pressed outward (**Figure 3502.03.09**)

The stationary region that follows is characterised by a uniform deformation strain and a uniform distortion of the volume elements. The vertical grid lines are parallel to the axis and the total deformation of an element is less than in the nonstationary region. If the die opening angle is large ($2\alpha > 120^\circ$), so-called "dead material zones", which do not participate in the main flow, are created behind the flowing material. The material flow in the „hollow forward“ impact extrusion behaves similar to the „solid forward“ impact extrusion but has a smaller displaced part during the movement of the material into the forming zone.

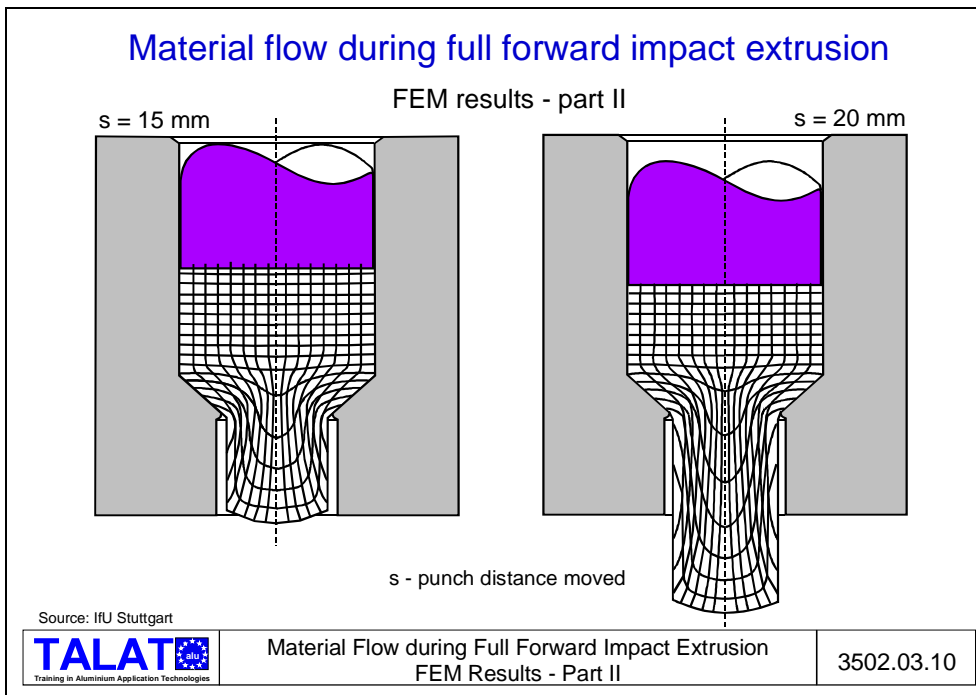
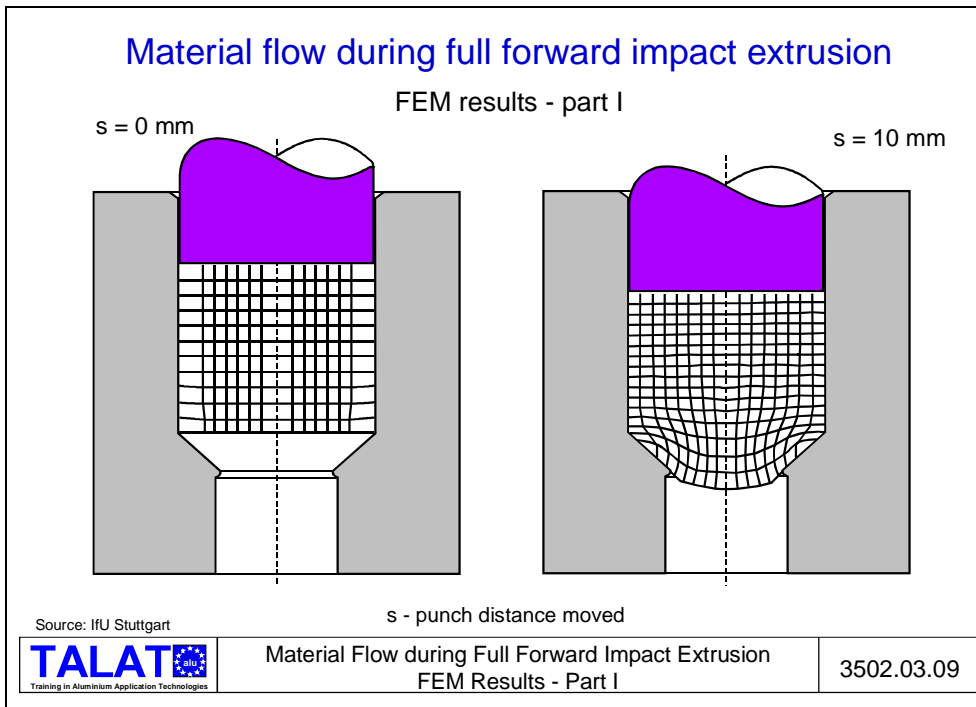
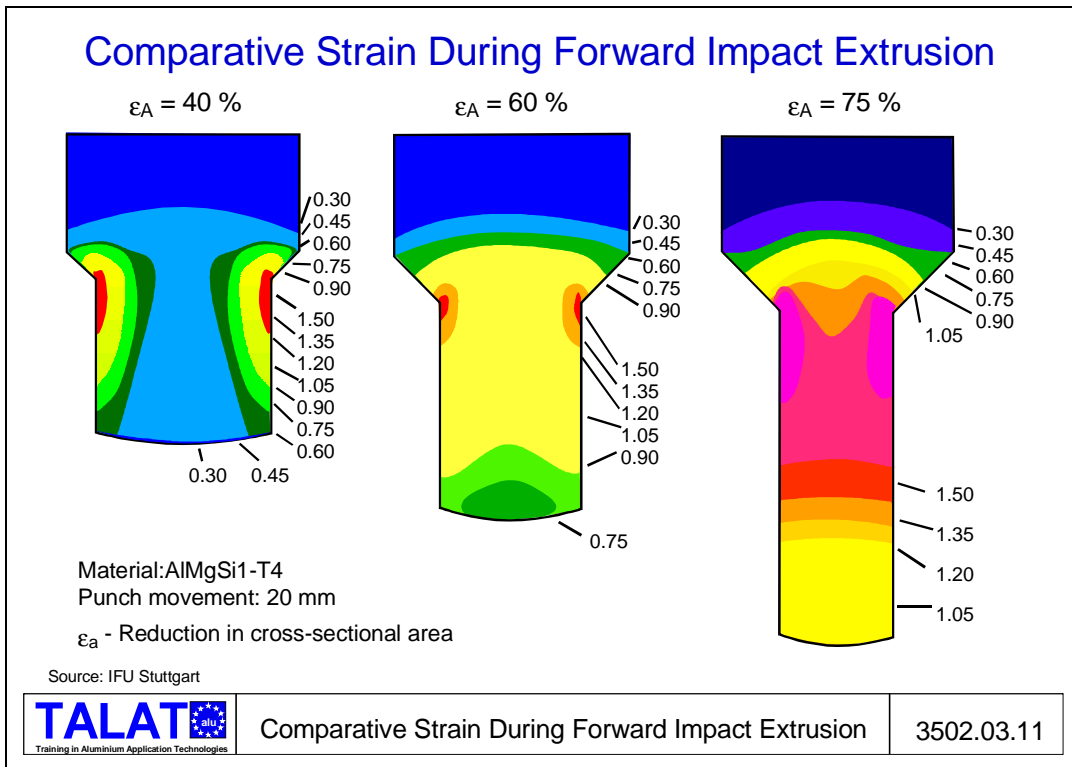
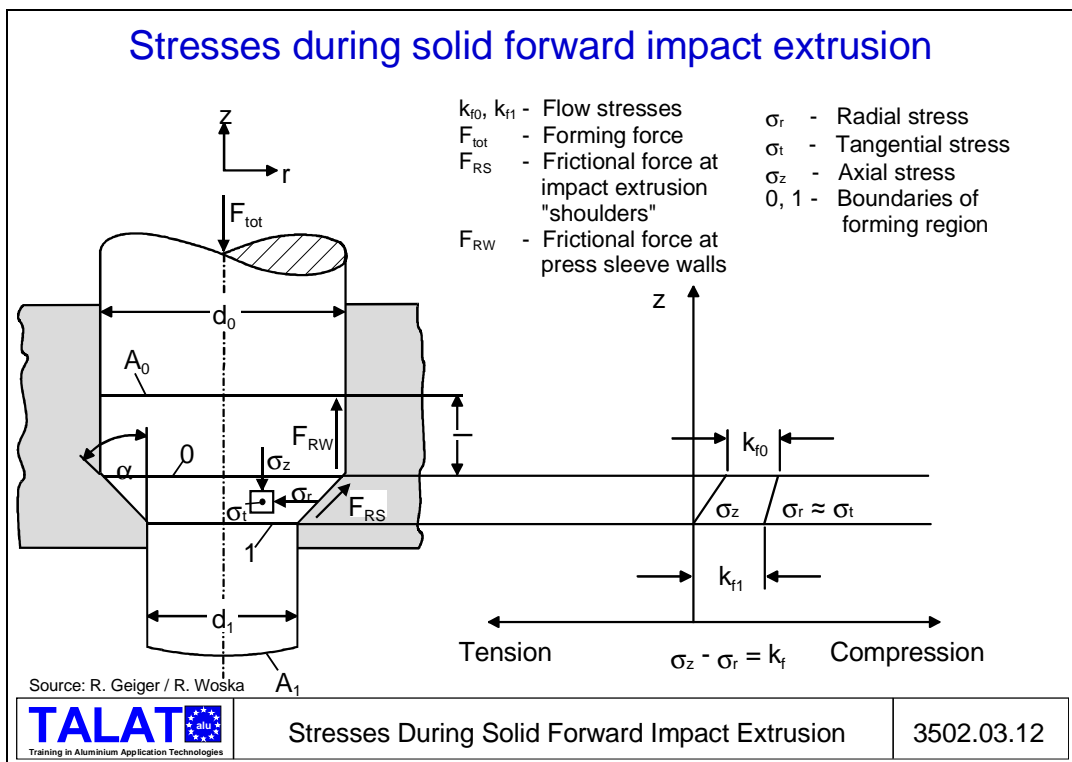


Figure 3502.03.11 shows the results of calculations of comparative strain during „solid forward“ impact extrusion. The comparative strain (deformation) during solid forward impact extrusion reaches a maximum value in the region of the die opening plane and decreases, the further one moves radially into the interior of the work-piece. The large change in the comparative strain distribution in the radial direction decreases with increasing reduction of cross-section.



Stresses

Stresses during solid forward impact extrusion are described in **Figure 3502.03.12**.

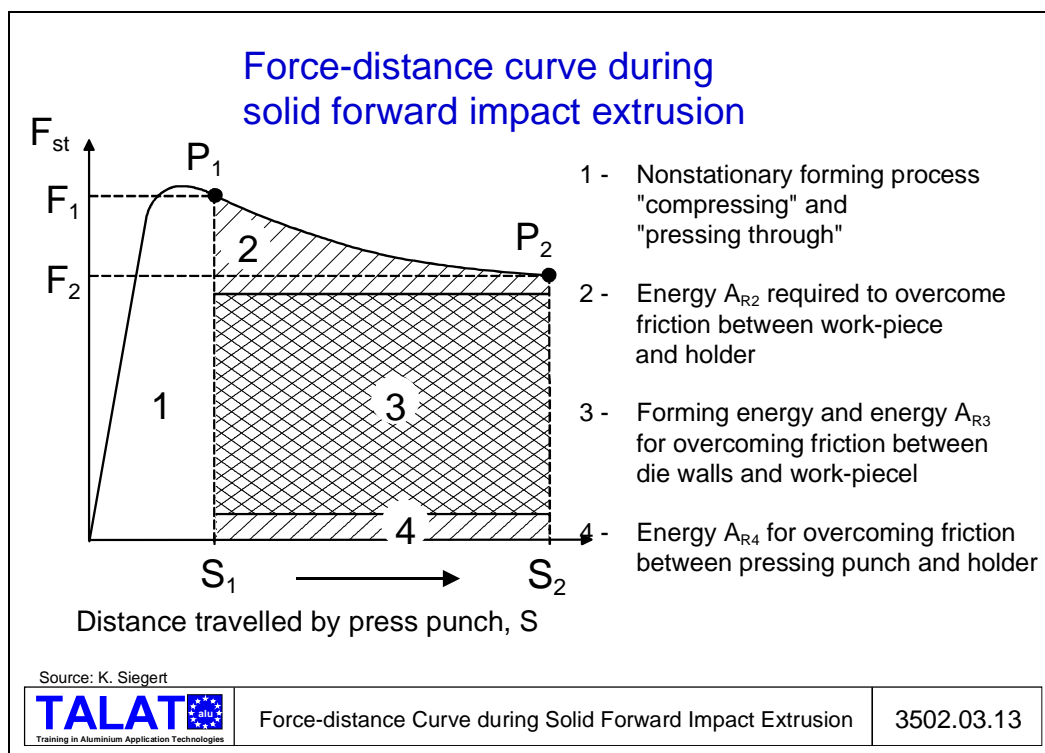


The forming force F_{tot} is applied through the punch. The deformation zone extends from plane 0, where the material is plastic, to plane 1. At the outlet of the opening, the material moves out without constraint so that the axial stress, $\sigma_z = 0$. From this plane onward, the axial stress increases in the strained zone as a compressive stress up to the plane 0 and attains the value $\sigma_{z0} = F_{tot}/A_0$. The principal stresses in the radial, σ_r and in the tangential, σ_t direction are equal. According to Tresca: $\sigma_r = \sigma_z - k_f$

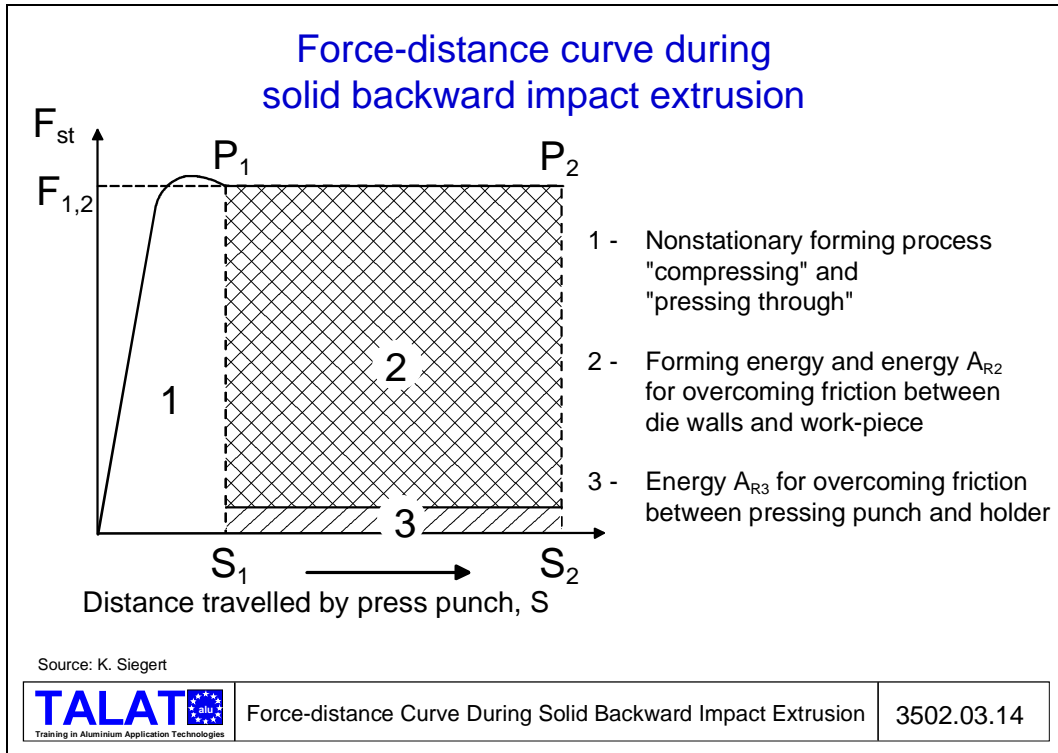
During hollow forward impact extrusion, a similar complex (3-dimensional) state of compressive stress with σ_r , σ_z and σ_t exists. The radial stress σ_r is the largest compressive stress. For thick-walled hollow bodies $\sigma_r \approx \sigma_t$, for thin-walled ones $\sigma_t \approx (\sigma_z + \sigma_r)/2$.

Force-Distance Curve

Figure 3502.03.13 illustrates a typical force-distance curve for a quasi-stationary impact extrusion operation using the solid forward impact extrusion process as an example. There is a rapid linear rise of the punch force due to the elastic deformation in the system tool - work-piece (region 1). The work-piece is pressed into the opening and deformed plastically. The maximum force attained is a result of both the deformation of the work-piece elements as well as the transition of the friction from static to dynamic at the impact extrusion "shoulder". The work against friction (A_{R2}) between the holder (container) and work-piece decreases with increasing deformation so that the force starts to drop. The deformation force, the frictional force between die walls and work-piece over the stroke as well as the frictional force between punch and container over the stroke remain constant during the stationary deformation process.



The force-distance curves for „solid backward“ impact extrusion are similar to those for „solid forward“ impact extrusion with the exception that the frictional energy A_{R1} required to move the work-piece in the holder does not have to be considered, see **Figure 3502.03.14**.



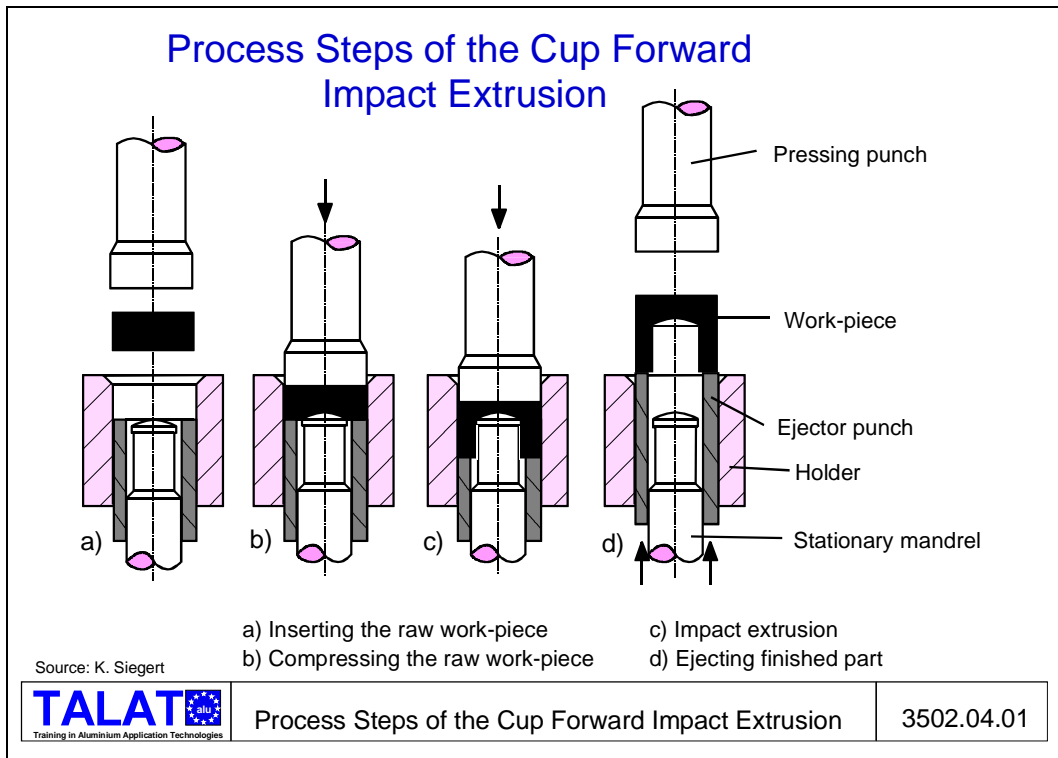
The force-distance curve for hollow impact extrusions is, in principle, similar to that for solid impact extrusions, with the exception that the frictional force acting between forming material and punch or between forming material and mandrel has also to be considered.

3502.04 Impact Extrusion with Non-stationary Material Flow

Process Steps

The basic processes cup forward, cup backward and lateral impact extrusion belong to the impact extrusion operations with nonstationary material flow, whereby the cup backward impact extrusion is the one more commonly used.

Figure 3502.04.01 illustrates the process steps of the „cup forward“ impact extrusion. The „cup forward“ impact extrusion differs from the solid forward impact extrusion in that the actual die is composed of the holder (container) and an immovable mandrel which together cause the work-piece material to replicate the interior contours of the cup.



In the cup backward impact extrusion the punch is forced into the forming material which is radially enclosed by the holder (container). An ejector punch builds the bottom of the container, see **Figure 3502.04.02**.

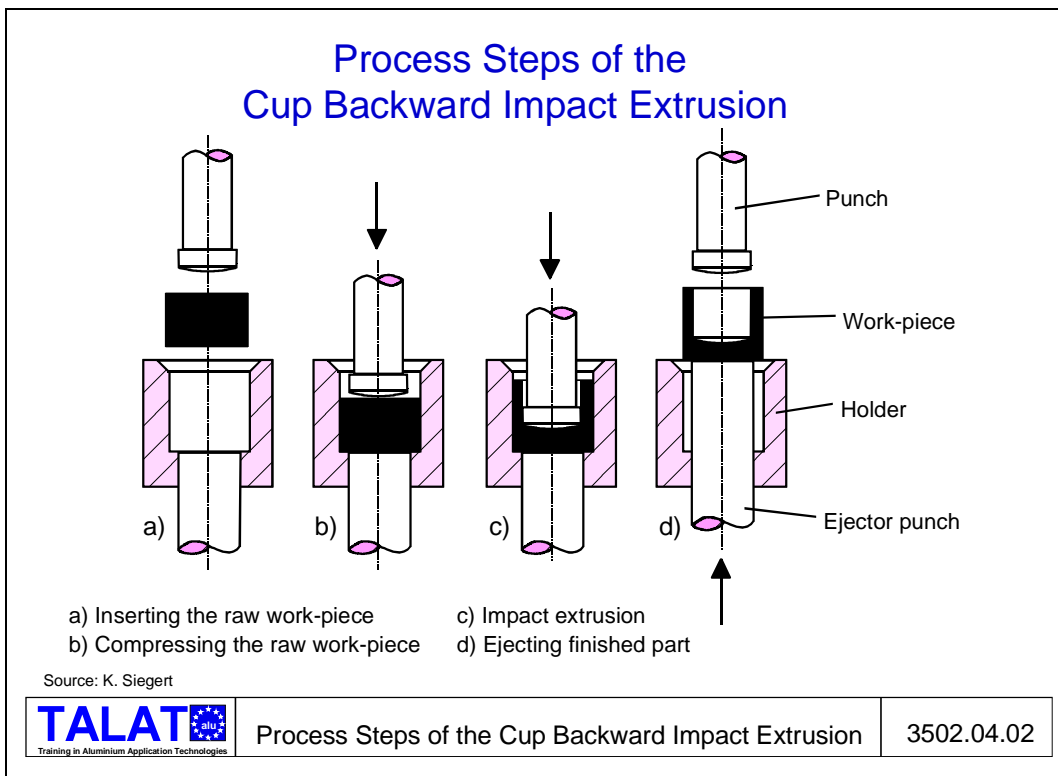


Figure 3502.04.03 shows the process steps during „solid lateral“ impact extrusion. The term lateral impact extrusion is applied to cover processes in which the material flows at

an angle (mostly 90 °) to the direction of movement of the punch. As opposed to compression in which similar forms can be created, the forming orifices remain here unchanged during the process. During lateral impact extrusion, the local deformation strain can reach values of up to $\epsilon_V = 5$. In order to create the lateral form elements, an additional vertical or horizontal splitting of the tool is necessary, together with a tool closing action coupled to the punch movement. For this purpose a multi-acting tool-machine system is necessary.

„Solid lateral“ impacts with pegs at 90° to the punch movement direction can be extruded using a transversely split container with a die arranged at right angles in the splitting (parting) plane. The pressing punches in the container halves, penetrate at the same speed, so that a pressing action, symmetrical to the splitting plane, is attained.

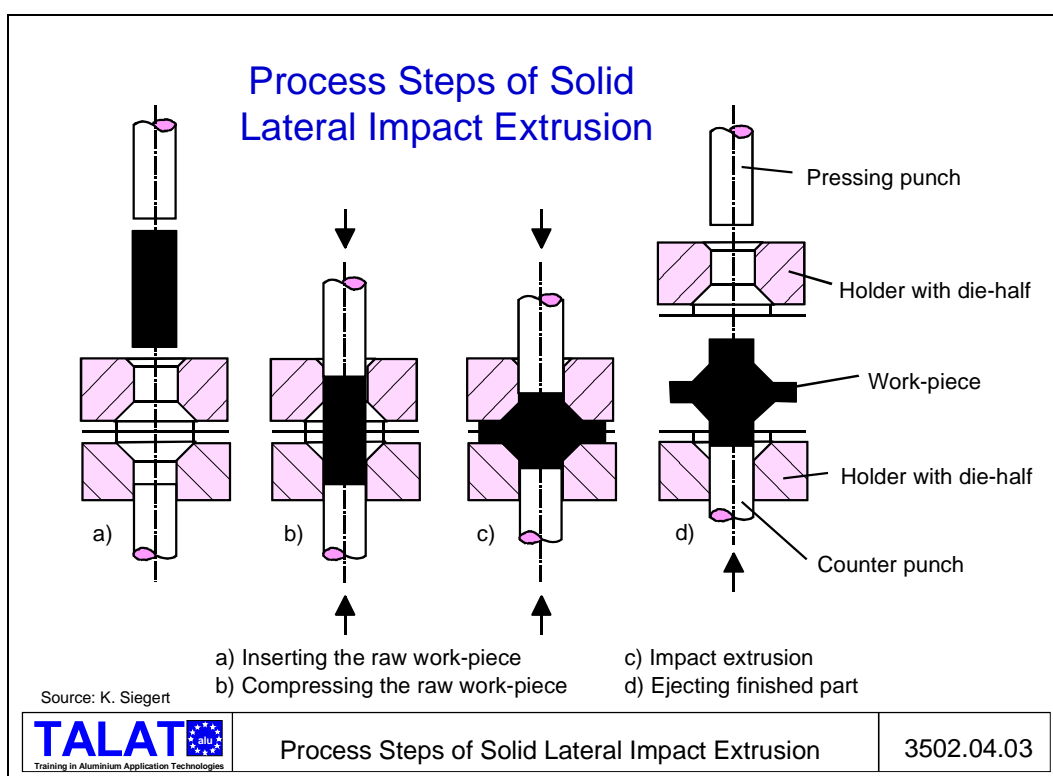
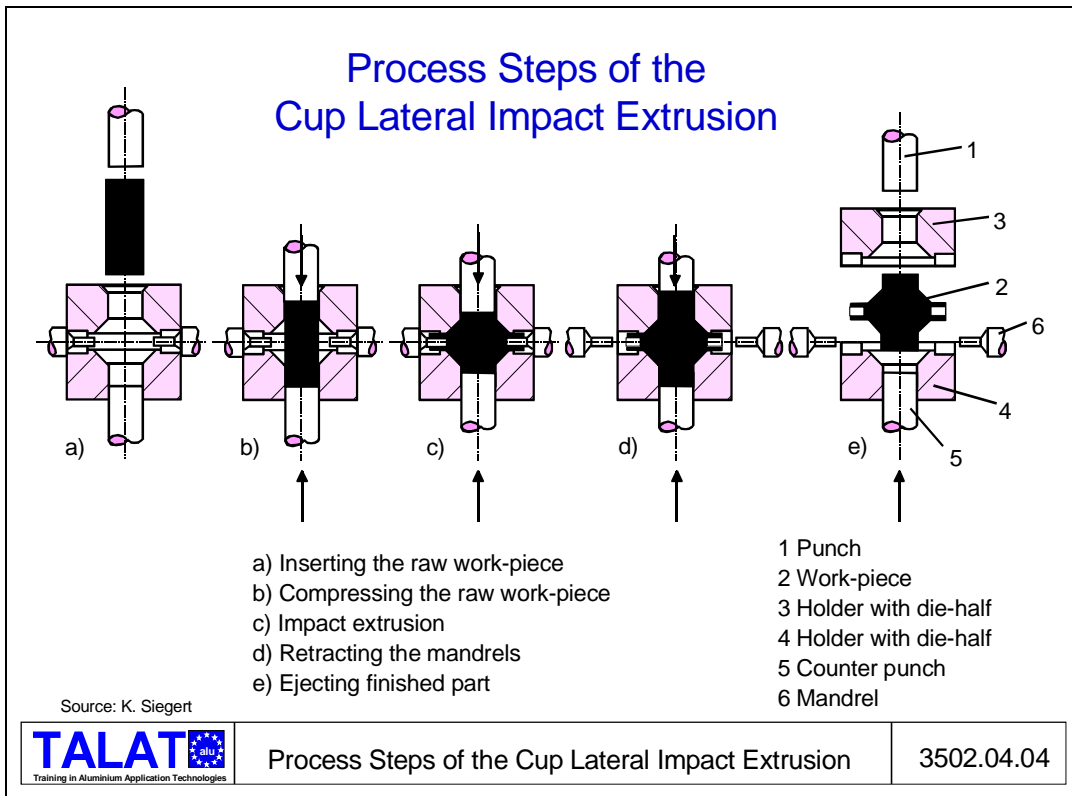
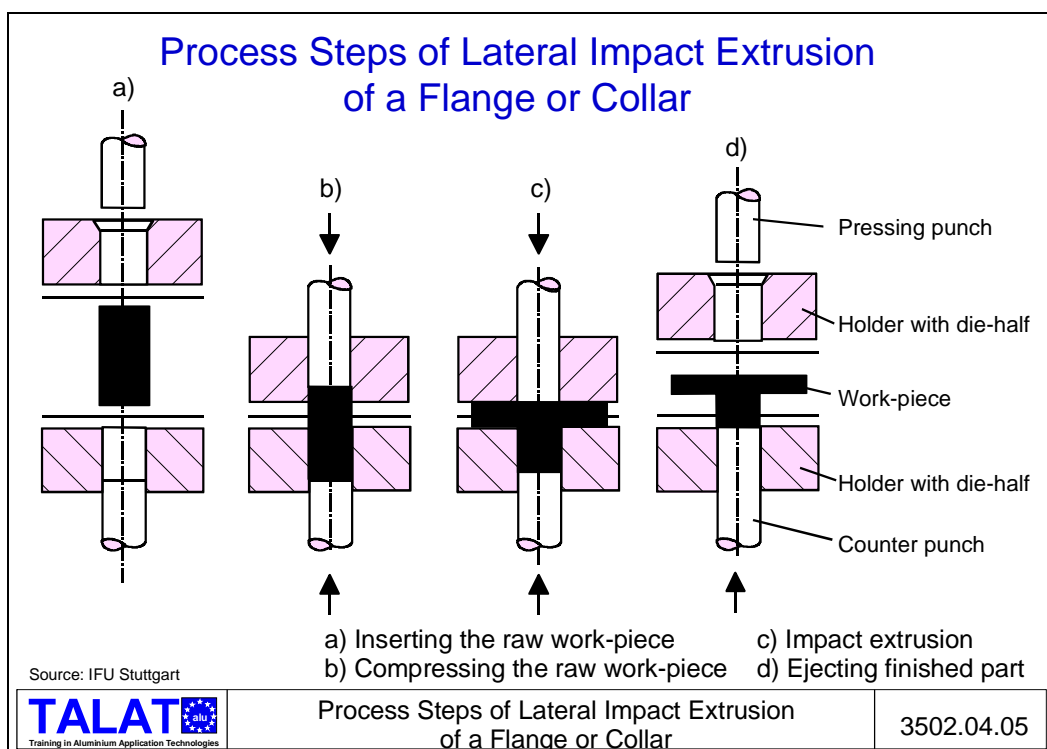


Figure 3502.04.04 shows the process steps during the „cup lateral“ impact extrusion. In the „cup lateral“ impact extrusion process, rigid mandrels are arranged in the splitting (parting) plane at right angles to the direction of punch movement. At the end of the impact extrusion process, these mandrels can be pulled radially out of the work-piece using mechanical or hydraulic systems. The actual tool can now be opened to remove the finished part.



Process steps during the lateral impact extrusion of a flange or collar are shown in **Figure 3502.04.05**. The process steps during the lateral impact extrusion of a flange or collar are, in principle, same as those for the solid lateral impact extrusion, with the difference that the die is hollowed out at the circumference of the splitting plane, so that a flange or collar can be formed during pressing.



Material Flow and Deformation

Material flow during „cup backward“ impact extrusion is illustrated in **Figure 3502.04.06**. During the penetration of the punch in the „cup backward“ impact extrusion, the material is first subjected to an axial compression which causes it to be pressed radially outward to the container walls and then to flow up against the direction of the punch movement, through the ring-formed orifice between punch and container. The material flows initially along the walls but may flow freely later-on. The ring-formed orifice corresponds to the wall thickness of the cup. Under the influence of the punch force, the forming material builds a hemispherical plastic region under the punch. The extent of this strained region depends on the geometrical conditions of the process like relative change in cross-section and base thickness of the cup. Due to the nonhomogeneous deformation process, the true deformation strain can only be approximately calculated by the equation $\varphi_g = \ln (A_0/A_1)$.

According to Dipper:

$$\varphi_m = \varphi_1(d_i/d_o)^2 + \varphi_2(d_o^2-d_i^2)/d_o^2$$

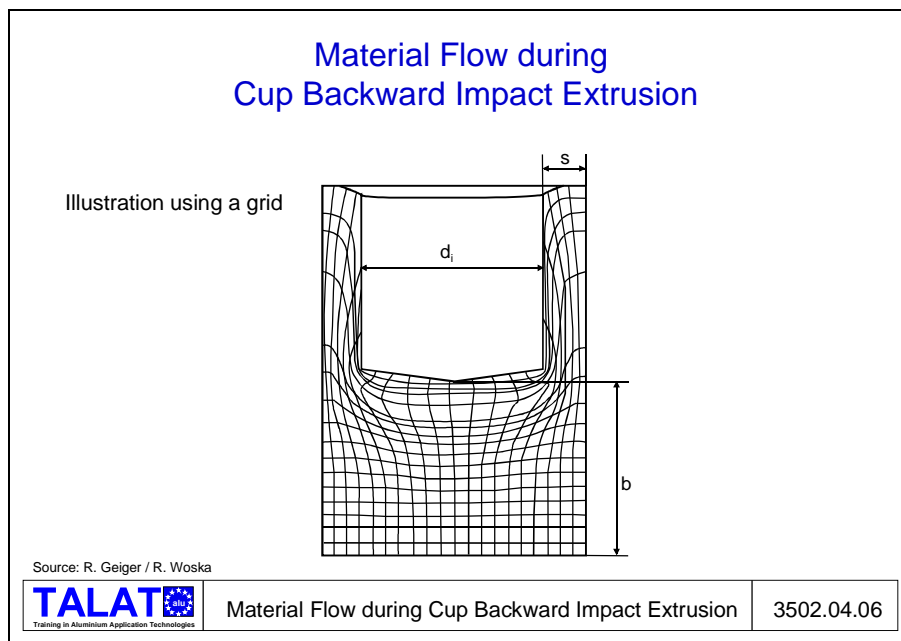
with the main strains $\varphi_1 = \ln(l_o/b)$

$$\varphi_2 = \varphi_1[1 + (d_i/8s)]$$

Usually one uses the reduction in area as the comparative characteristic value

$$\varepsilon_A = (A_0 - A_1)/A_0$$

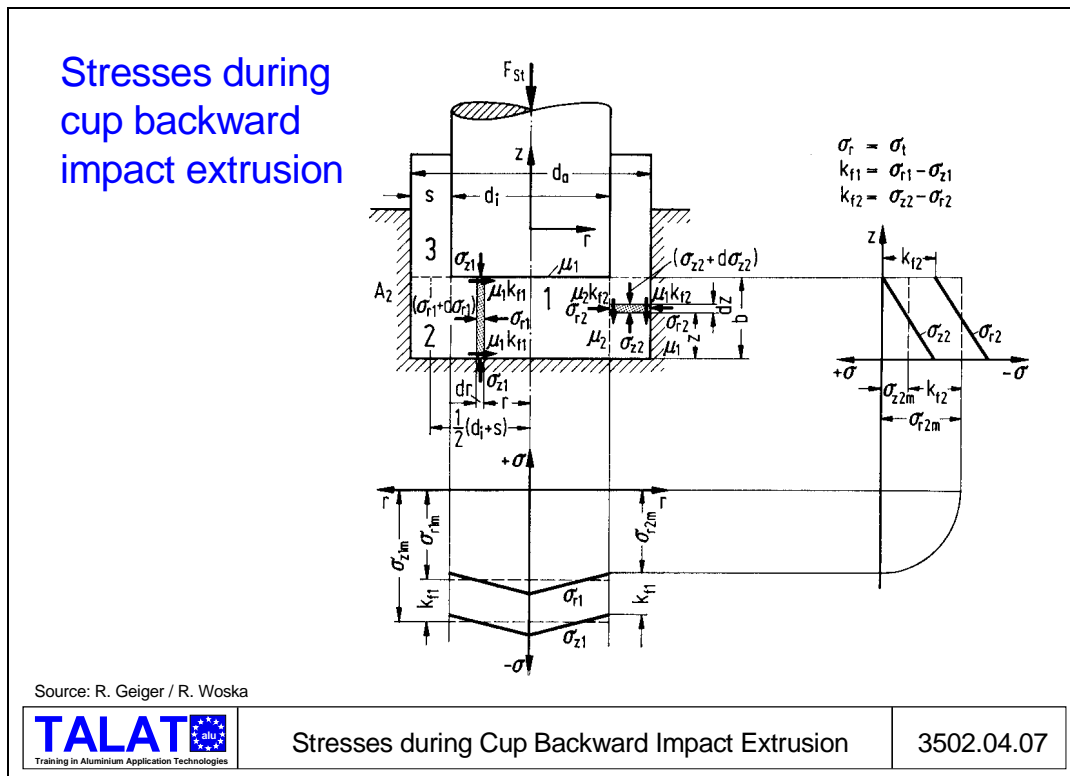
The distribution of the comparative strain for the cup backward impact extrusion is clearly nonhomogeneous, which means that we are clearly dealing with a nonstationary process. The largest strain occurs at the no-slip point. A double-sided application of force causes the material to flow most uniformly in the secondary form elements, because no motionless material regions and no abrupt speed gradients occur.



Stresses

A three-dimensional state of compressive stress exists also during the „cup backward“ impact extrusion. Because of the strongly non-homogeneous straining, determining the local stresses is highly complicated. A model process is used as a basis for determining the stresses analytically. In Dipper's model, the „cup backward“ impact extrusion is assumed to be a double compression process.

Figure 3502.04.07 shows the stresses in the „cup backward“ impact extrusion process. The starting slug is first compressed between the punch of diameter d_i and the die bottom (zone 1). The material which is pressed outwards reaches the die walls and is compressed once more to deliver the required wall thickness (zone 2). The material which is pressed through the ring-formed orifice between punch and container (zone 3) is considered to be motionless. This assumption is valid for thin-walled cups with $\epsilon_A \geq 0.5$. Both compression processes are considered to be homogeneous deformation processes.



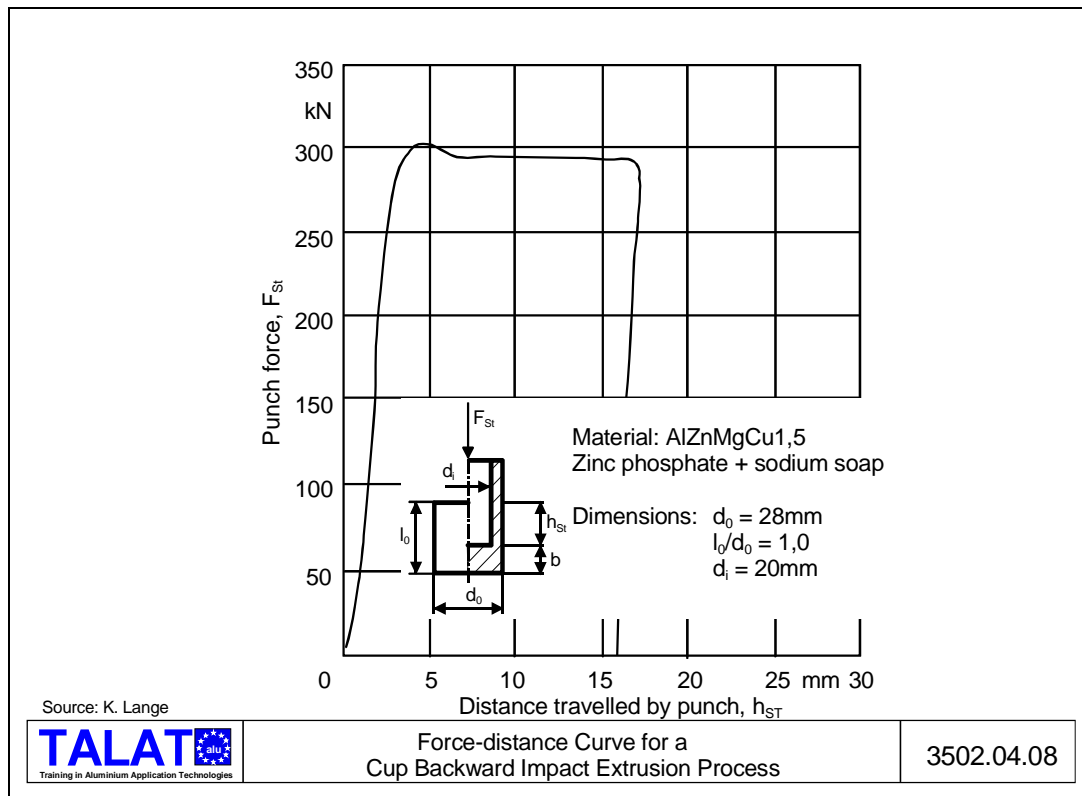
Radial and axial compressive stresses as well as tangential stresses occur during the lateral impact extrusion of flanges and collars. When the tangential stress exceeds the flow stress, necking and cracking occur in the flange.

When laterally extending form elements are lateral impact extruded, the state of stress can be defined as being compressive.

Force-Distance Curves

Figure 3502.04.08 illustrates a characteristic force-distance curve for a cup impact extrusion. On the whole, this corresponds to the curve for punch force as a function of punch stroke during „solid backward“ impact extrusion. The measured punch force, F_{St} rises rapidly up to a maximum value which is reached when the punch penetrates into the forming material, and then remains almost constant or falls slightly. For large ϵ_A values, a peak force value is attained at the beginning, corresponding to the transition of friction from static to dynamic. The maximum force, $F_{St \max}$ increases with increasing k_f , ϵ_A and d_o . In the range $0.15 < \epsilon_A < 0.6$, it depends additionally on the ratio l_o/d_o . When the remaining bottom thickness, b , is very small, a small increase of force is observed. This is mainly a result of the increasing axial compressive force.

The „cup forward“ impact extrusion process has higher frictional losses in the press die and, therefore, requires higher forces than the cup backward impact extrusion process.



3502.05 Combined Processes

The following figures illustrate the various combinations of the basic impact extrusion processes, in order to achieve a multitude of section shapes:

Figure 3502.05.01: Combined „solid forward“ and „cup backward“ impact extrusion

Figure 3502.05.02: Combined „cup forward“ and „cup backward“ impact extrusion

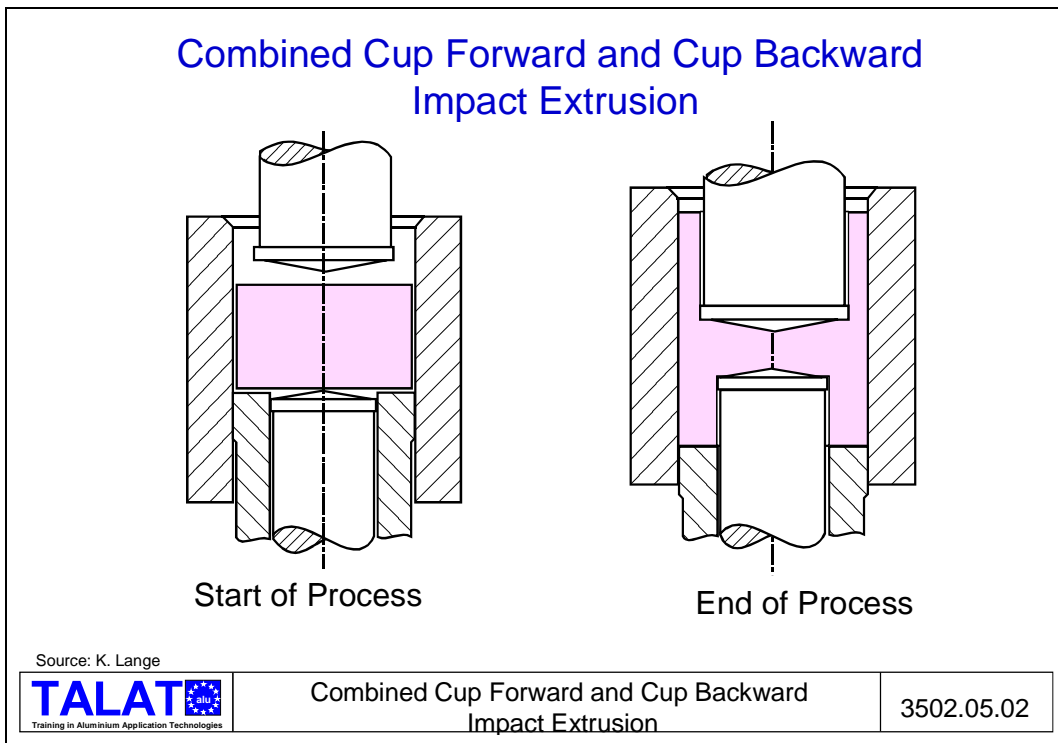
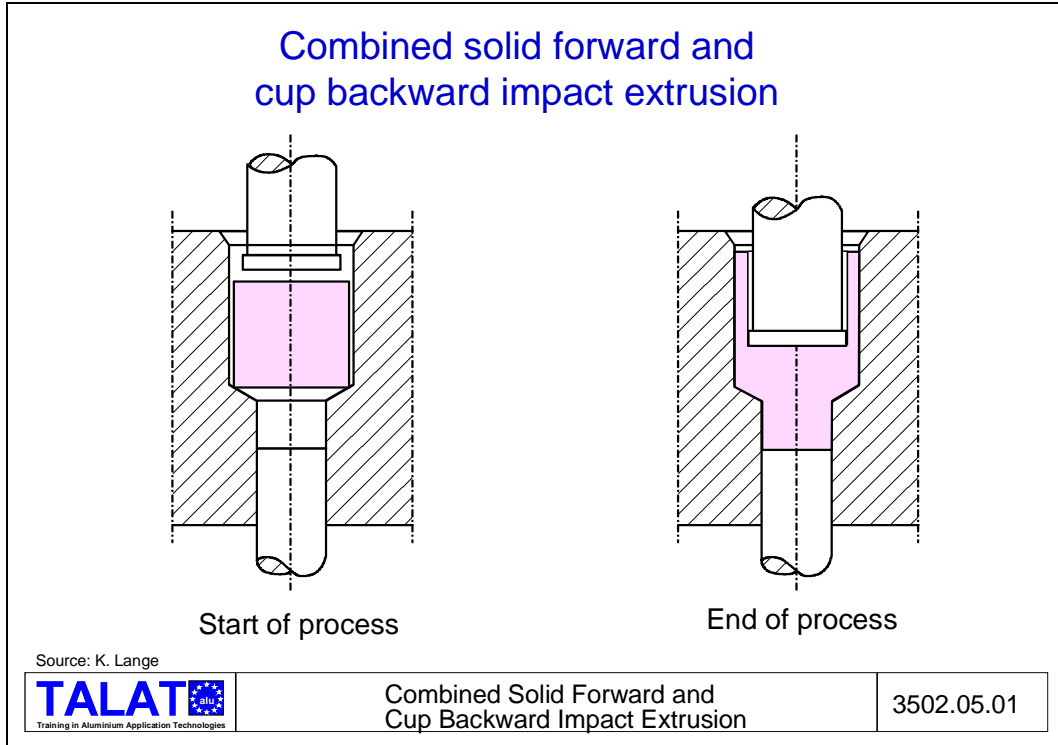
Figure 3502.05.03: Combined „cup backward“ impact extrusion

Figure 3502.05.04: Combined „solid backward“ and „cup backward“ impact extrusion

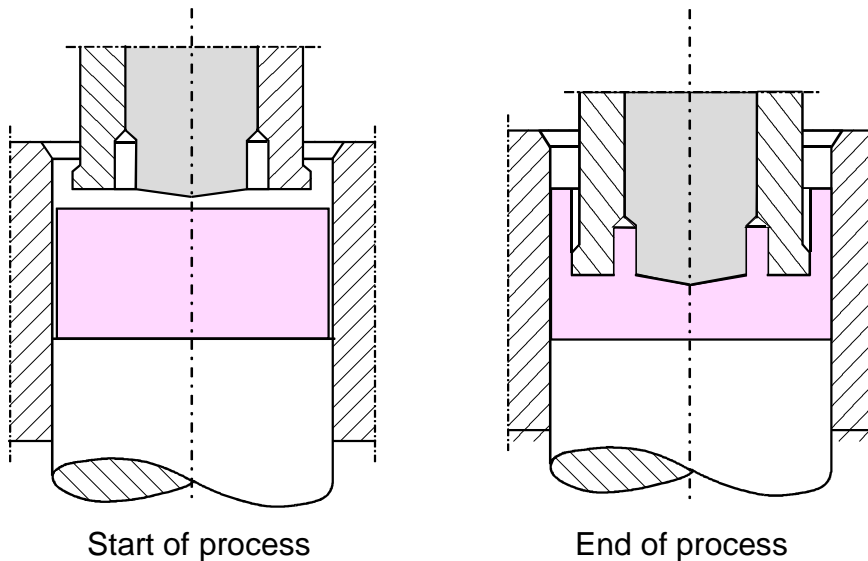
Figure 3502.05.05: Combined „lateral“ and „cup forward“ impact extrusion

Figure 3502.05.06: Combined processes - I

Figure 3502.05.07: Combined processes - II



Combined cup backward impact extrusion



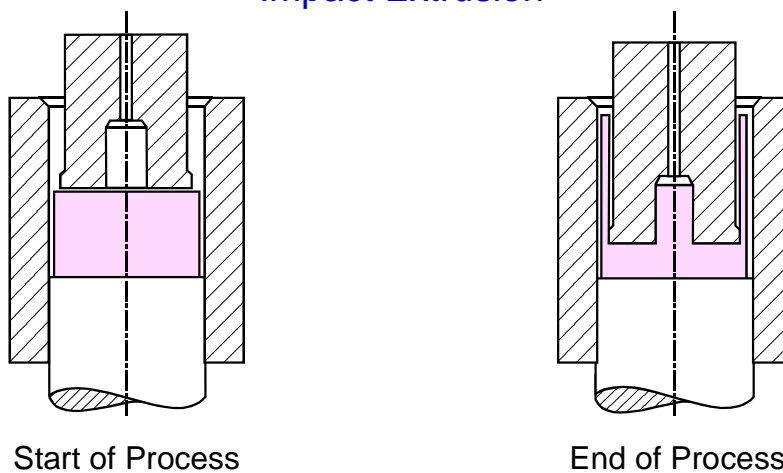
Source: K. Lange



Combined Cup Backward Impact Extrusion

3502.05.03

Combined Solid Backward and Cup Backward Impact Extrusion



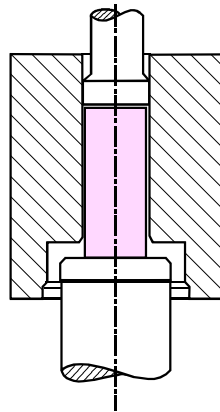
Source: K. Lange



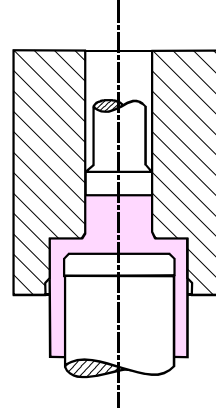
Combined Solid Backward and Cup Backward Impact Extrusion

3502.05.04

Combined Lateral and Cup Forward Impact Extrusion



Start of Process



End of Process

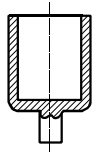
Source: K. Lange



Combined Lateral and Cup Forward
Impact Extrusion

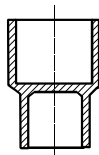
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Combined Processes - I



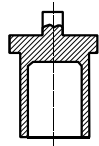
Backward hollow with forward solid impact extrusion

Shells with massive base external shaft, e.g. condenser cups are fabricated according to this process variation.



Backward hollow with forward hollow impact extrusion

Shells with intermediate bases are mostly fabricated using this process variation.
The two shell parts may have different diameters.



Backward solid with forward hollow impact extrusion

Shells with collar and external shaft are fabricated using this process variation.

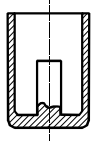
Source: Aluminium-Zentrale



Combined Processes - I

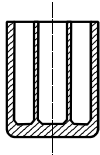
3502.05.06

Combined Processes - II



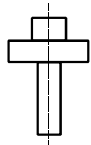
Backward hollow with backward solid impact extrusion

Used, for example, for shells with massive internal shafts.



Backward hollow with backward hollow impact extrusion

This process is used to fabricate shells with hollow internal shafts or for multi-walled shells.



Backward solid with forward solid impact extrusion

Massive parts, e.g. shafts with collars, can be made using this process.

Source: Aluminium-Zentrale



Combined Processes - II

3502.05.07

A difference is made here between processes which occur sequentially and those which occur simultaneously.

In processes which occur sequentially, the material flow is controlled by the movements of the active (movable) parts.

In processes which occur simultaneously, the material can flow simultaneously through different orifices, so that the geometry of the newly formed part cannot be precalculated solely on the basis of the dimensions of the starting slug, the tool geometry, and the law of volume constancy. The material flow in such processes is, therefore uncontrolled. Forming by using process combinations in which the material flow is uncontrolled leads to problems, because the flow lengths and forces required cannot be precalculated with any measure of accuracy.

The material in a combined forming process can only flow in different directions when the resistance to flow in these directions is the lowest (principle of the lowest resistance).

Material flow in the combined „solid forward“ and „cup backward“ impact extrusion is illustrated in **Figure 3502.05.08**. During the simultaneous flow of material in different directions and depending on the geometrical conditions, a no-slip point is created. If the material flow in one direction encounters a hindrance or is stopped, the no-slip point moves in the direction of the hindered material flow or disappears.

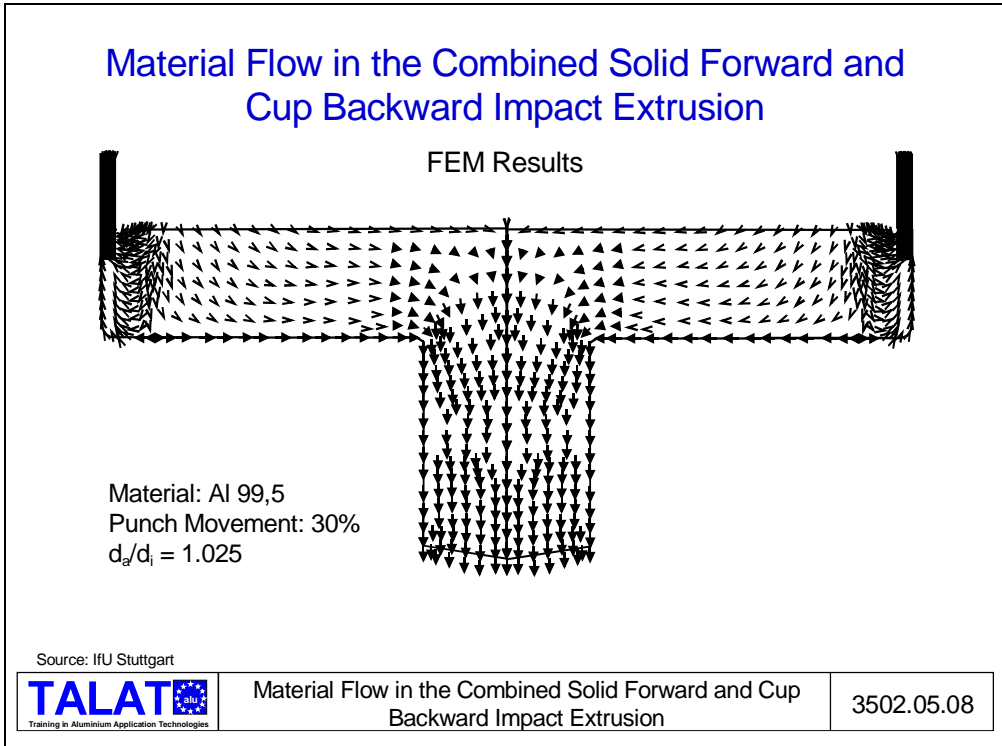
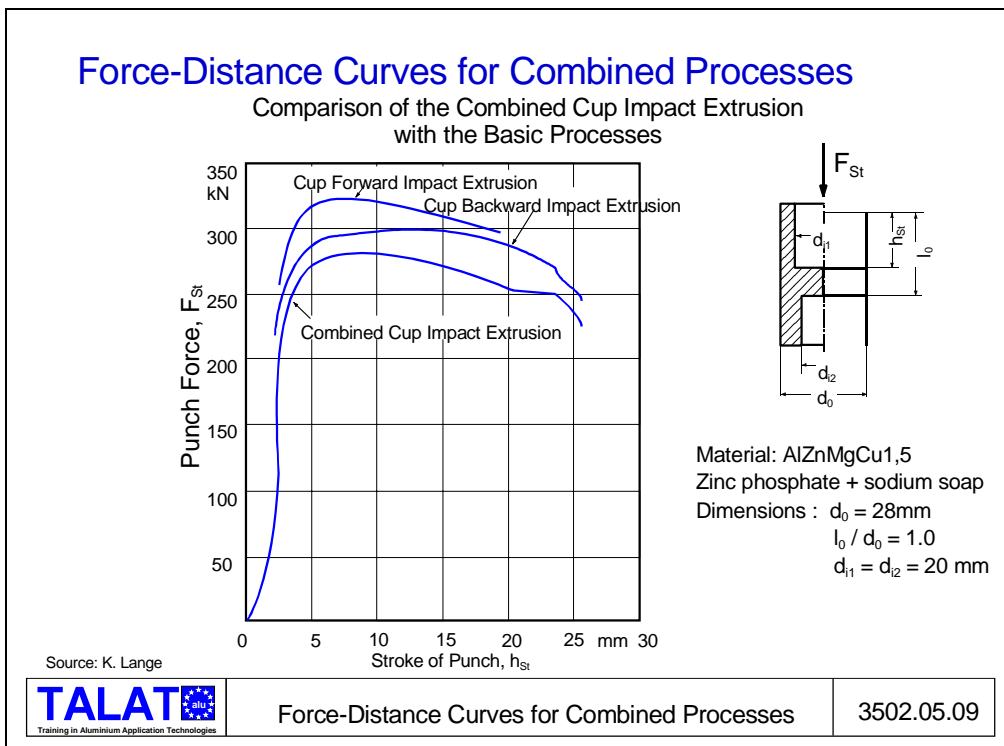


Figure 3502.05.09 shows the force-distance curve during combined processes. The force required for all combined processes in which simultaneous unhindered flow occurs, is smaller or at the most equal to the force needed for the process which requires the lower force. For different relative cross-sectional strains, ϵ_A , in the partial processes, the total force required for the combined process is equal to the force requirement for the partial process with lower ϵ_A . The forming process is self-controlling. At any moment of time, a minimum of forming power is required.



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