TALAT Lecture 3801

Manufacturing Examples and Fundamentals

14 pages, 20 figures

Advanced Level

**prepared by K.Siegert and T. Werle, Institut für Umformtechnik,
Universität Stuttgart**

Objectives:

– to describe the fundamentals of the superplastic behaviour phenomenon of aluminium alloys and the basic process parameters which govern the manufacturing of superplastic sheet metal parts

Prerequisites:

– General background in production engineering and material science

Date of Issue: 1994

3801 Manufacturing Examples and Fundamentals

Table of Contents

Note: Literature/References at the end of TALAT Lecture 3805

Superplastic Sheet Shaped Components

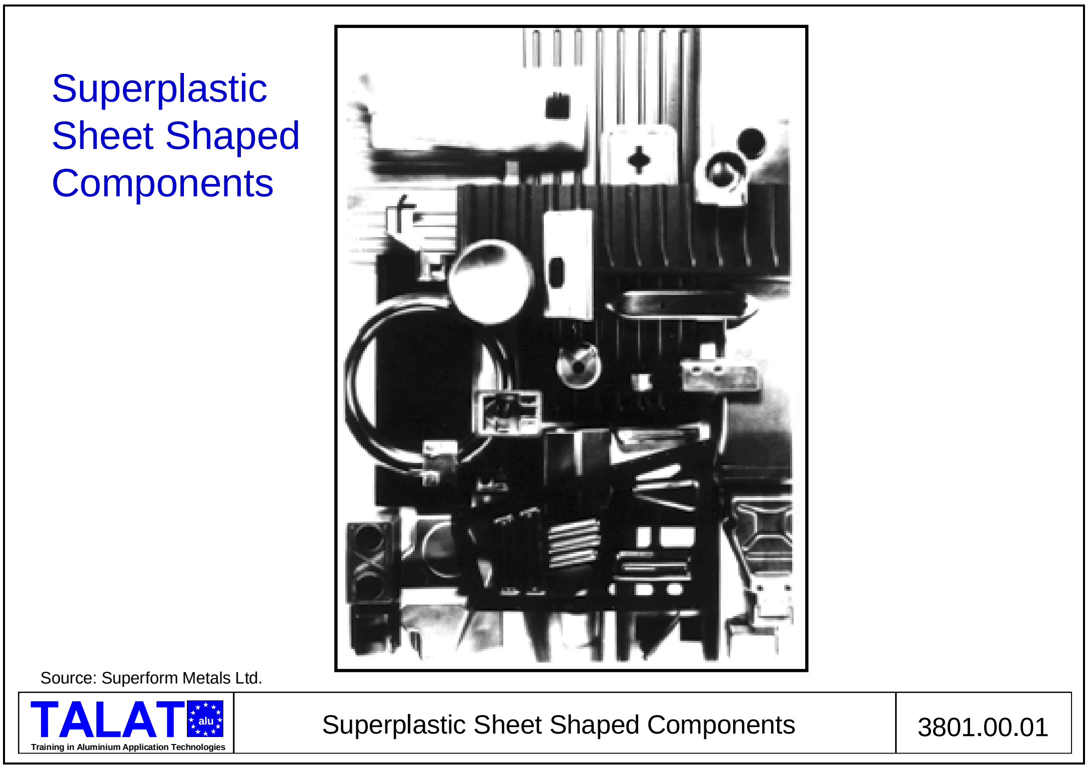
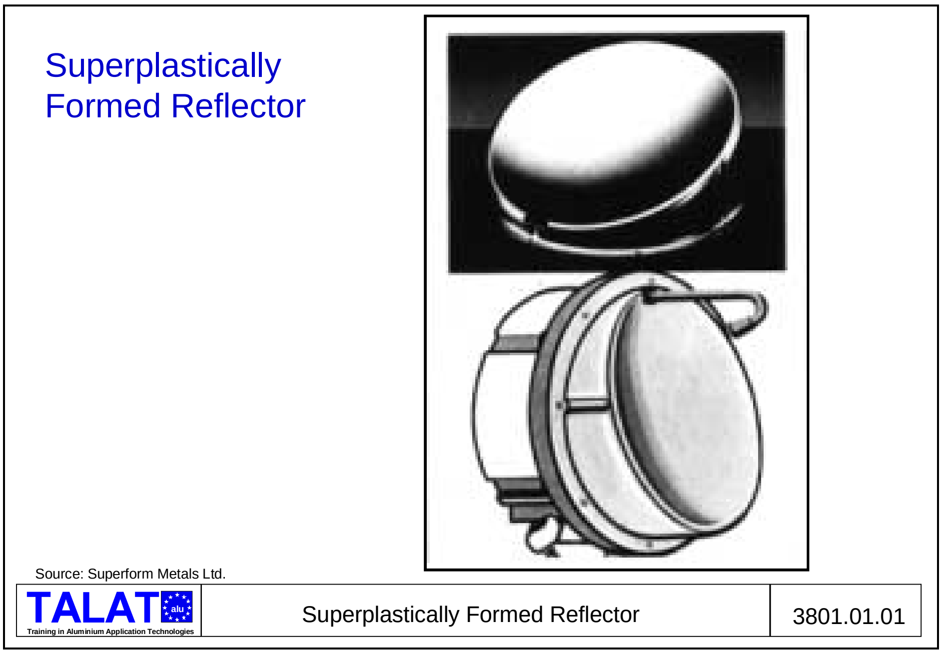


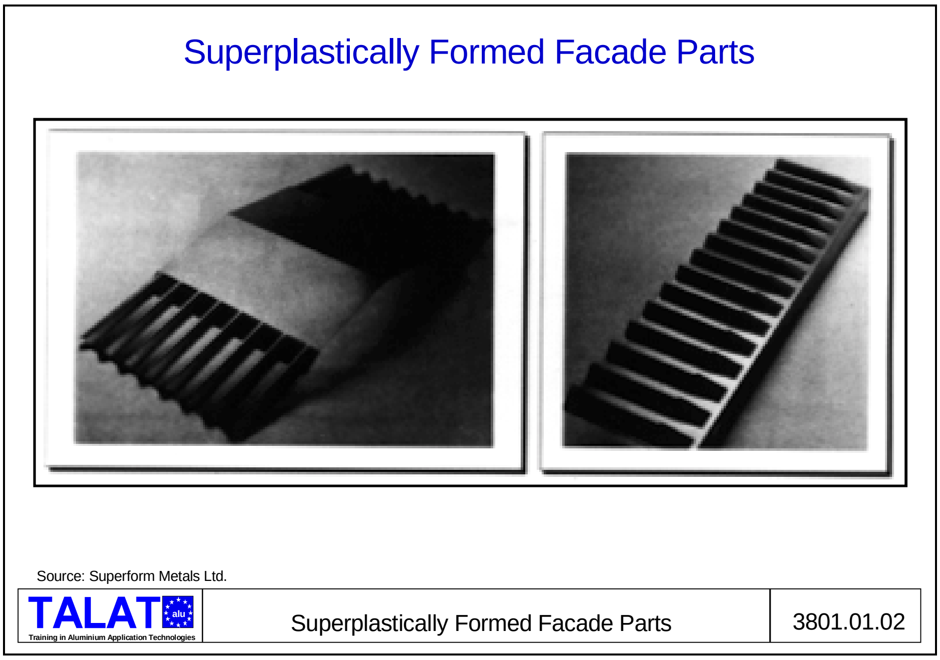
Figure 3801.00.01 gives some examples of superplastically formed aluminium parts of the company Superform Metals Ltd., England. The complex components shown are all fabricated in a low series production. Examples of superplastically formed parts are side panels of aeroplanes, facade elements, heat exchangers, gear boxes, fuel tanks, reflectors etc.

The superplastically formed reflector shown in **Figure 3801.01.01** has very large differences in drawing depths, making it difficult to produce the part with conventional sheet forming methods. Furthermore, the part has reentrant form segments at the circumference and a convex base, which can only be produced with additional sets of tooling with standard sheet forming processes.



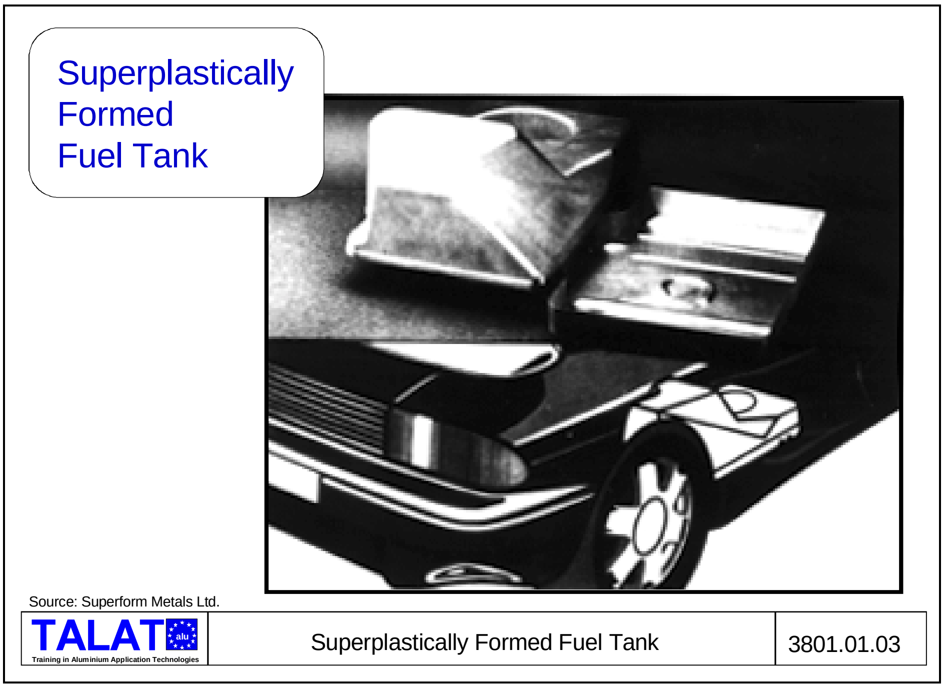
Superplastically Formed Reflector 3801.01.01

Figure 3801.01.02 shows superplastically formed building facade parts with a design which makes it extremely difficult to produce using conventional fabrication methods. The part on the left has two tilted surfaces ending in transverse ribs. A complicated material flow occurs at the transition zone. The extreme stretch forming process occurring here causes problems during cold forming. The high ribs prevent or hinder the transverse flow of material, which is further complicated by the sharp radii.



Superplastically Formed Facade Parts 3801.01.02

Large differences in drawing depth, reentrant corners and slanting body forms lead to problems during manufacturing with cold forming methods. The superplastically formed tank shown in **Figure 3801.01.03** is a good example of very complex sheet shaped parts.



Definition of Superplastic Forming

The technical definition of superplastic forming as given in **Figure 3801.01.04** has been obtained from existing literature. It must be noted here that failure occurs due to a break up of the grain structure and not due to local necking as observed during tensile testing.

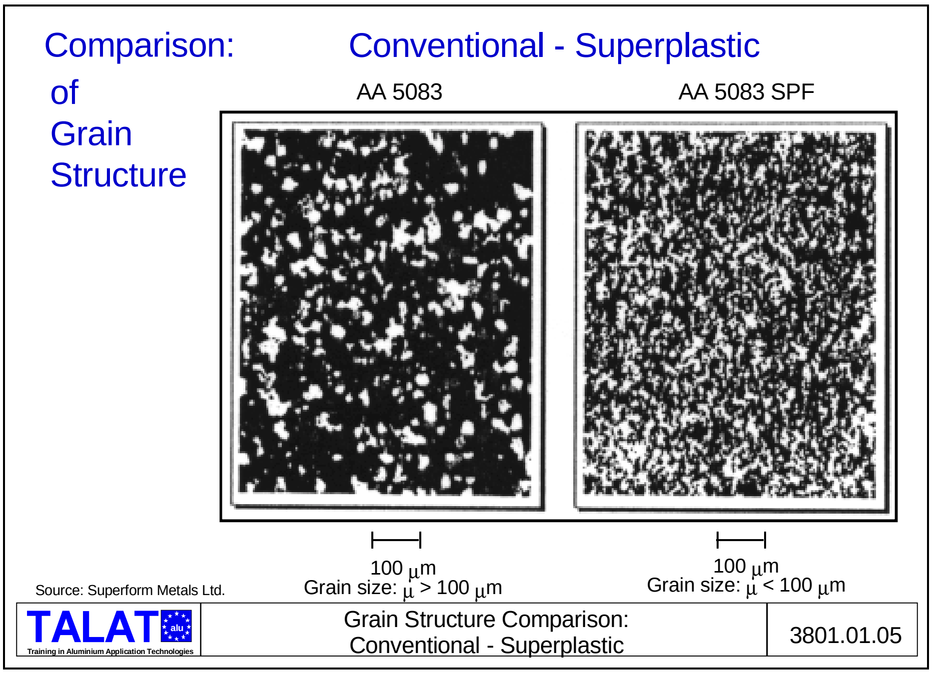
Technical Definition of Superplastic Forming

Superplasticity is that property of materials which makes it possible to obtain extremely large uniform and rupture elongations under pure tension loading.

TALAT – Training in Aluminium Application Technologies	Technical Definition of Superplastic Forming	3801.01.04

Fundamentals of Superplastic Behaviour

Figure 3801.01.05 shows the grain structure of the alloy AA 5083 in its conventional form and in the superplastic variation. Superplastic quality requires homogeneity, isotropy and extreme fineness of the grain structure, which is not normally achievable in standard sheet metal production



Grain Structure Comparison: Conventional - Superplastic 3801.01.05

The metallurgical requirements of materials for superplastic forming are listed in **Figure 3801.01.06**. The material must have a high resistance to grain growth and formation of pores. The stability of the grains, i.e. a high resistance to grain growth, is an essential material requirement, since the superplastic forming process for aluminium alloys is carried out at elevated temperatures and thus constitutes a thermally activated process.

Metallurgical Requirements of Materials for Superplastic Forming

- Very fine grains: $2 < d < 10$ (20) μm
- High resistance to grain growth
- Strain rate has a very pronounced effect on the flow stress k_f
- High resistance to formation of pores

TALAT — Training in Aluminium Application Technologies | Metallurgical Requirements of Materials for Superplastic Forming | 3801.01.06

The basic process requirements for superplastic forming are summarized in **Figure 3801.01.07.** These requirements indicate the economical problems associated with the superplastic forming process. The extremely low straining rate leads to production times extending from about 5 minutes to a few hours.

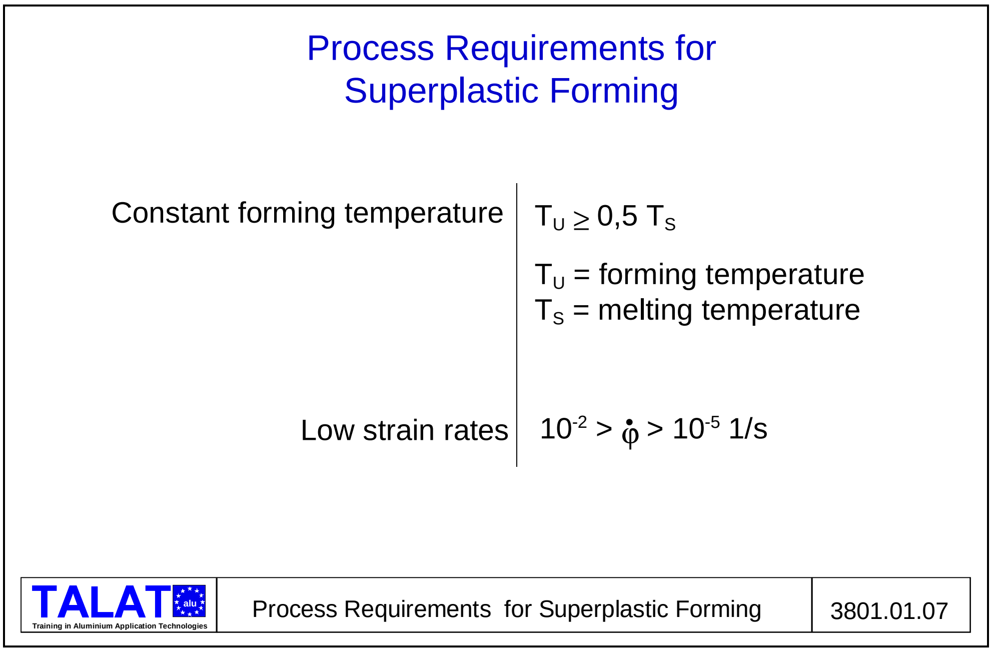


Figure 3801.01.08 underlines the advantages and special technological properties of superplastic materials. Since the flow stress values are low, small forming forces are required which lead to low tool stresses. The potential of large uniform elongation properties provides optimum performance under severe stretch forming conditions.

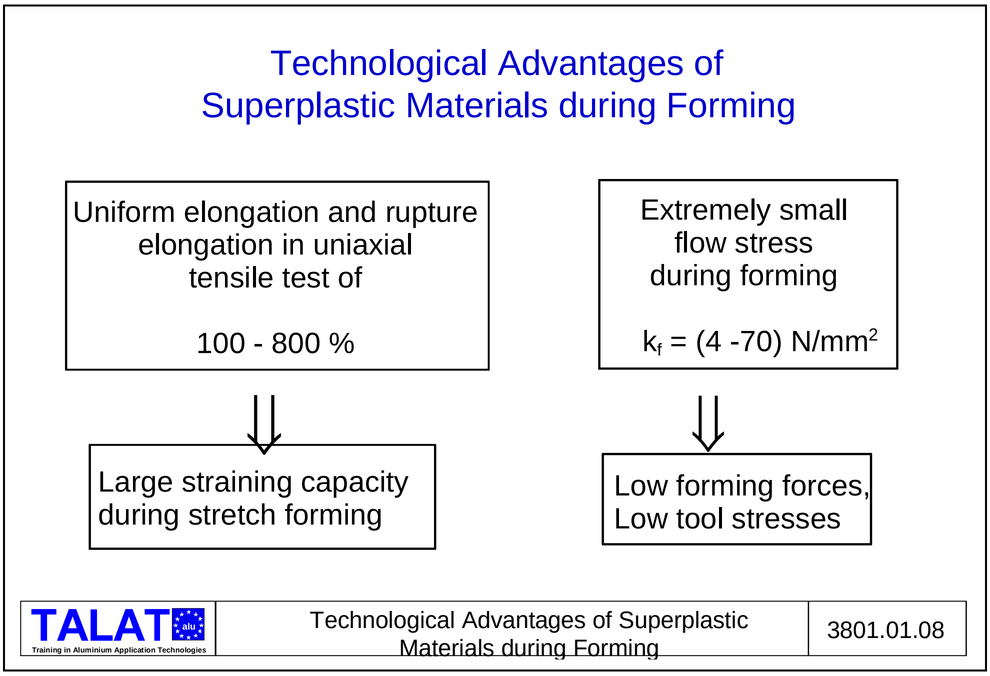


Figure 3801.01.09 describes the general material law for plastic deformation according to Ludwik. The Ludwik material law gives the flow stress as a function of the logarithmic value of strain (or true strain), the strain hardening exponent, the log. strain rate and the rate coefficient. It is worth mentioning the fact that almost no strain hardening occurs during warm forming, i.e. the flow stress during superplastic forming is not affected by the degree of plastic strain. The equation is then reduced to $k_f = C \cdot \dot{\varphi}^m$, which is given in **Figure 3801.01.10.** Here, the importance of the exponent *m* for the superplastic forming behaviour of materials becomes obvious. The flow stress depends on the logarithmic strain rate and the strain rate exponent *m*. If the logarithmic strain rate is kept constant for a forming process, then the flow stress required depends only on the strain rate exponent *m*. The following figure depicts the principle of the effect on the material flow behaviour.

Material Law according to Ludwik

$$k_f = C\ \varphi^n\ \dot{\varphi}^m$$

k_f flow stress

$\dot{\varphi}$ logarithmic strain rate

C material constant

n strain hardening coefficient

φ logarithmic strain

m rate exponent

TALAT Training in Aluminium Application Technologies | Material Law according to Ludwik | 3801.01.09

Flow Stress according to Ludwik

$$K_f = C\ \dot{\varphi}^m$$

k_f flow stress

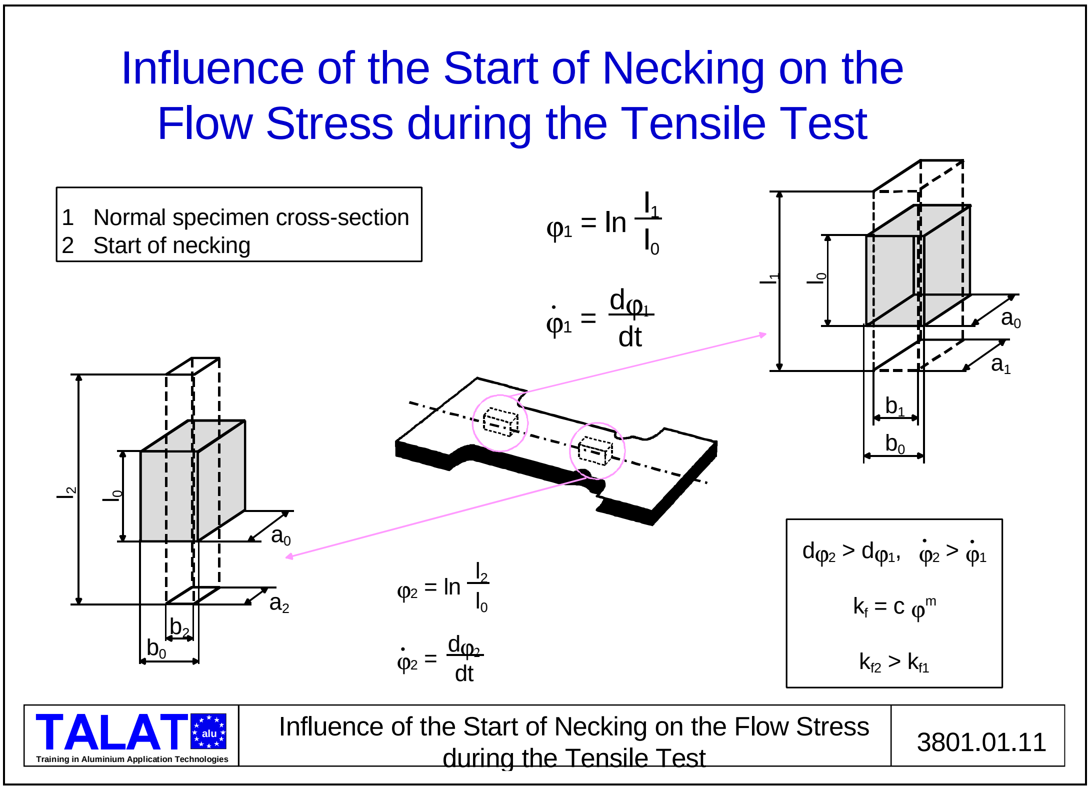
$\dot{\varphi}$ logarithmic strain rate

C material constant

m rate exponent

TALAT Training in Aluminium Application Technologies | Flow Stress according to Ludwik | 3801.01.10

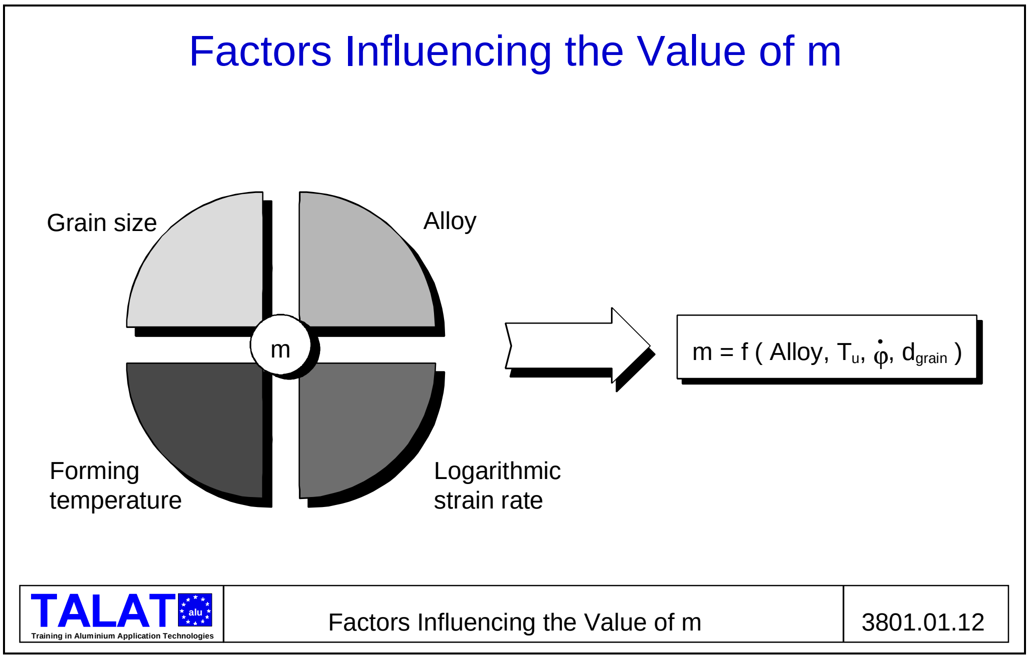
Figure 3801.01.11 shows the momentary state of a tensile specimen under constant strain rate. When the local necking starts, different rate conditions become valid. In the necked region 2, the instantaneous local logarithmic strain rate is larger than in the region 1 without necking. Since the logarithmic strain rate is the differential of the logarithmic strain with respect to time, the strain in region 2 is greater than in region 1. The flow stress k_f, as explained in **Figure 3801.01.10**, depends on the logarithmic strain rate. In the case of superplastic forming, this leads to an increase of flow stress in the necked region. The material flow is, therefore, displaced to the regions outside the necked region. This strain-rate-hardening effect in the necked region balances the necking tendency.

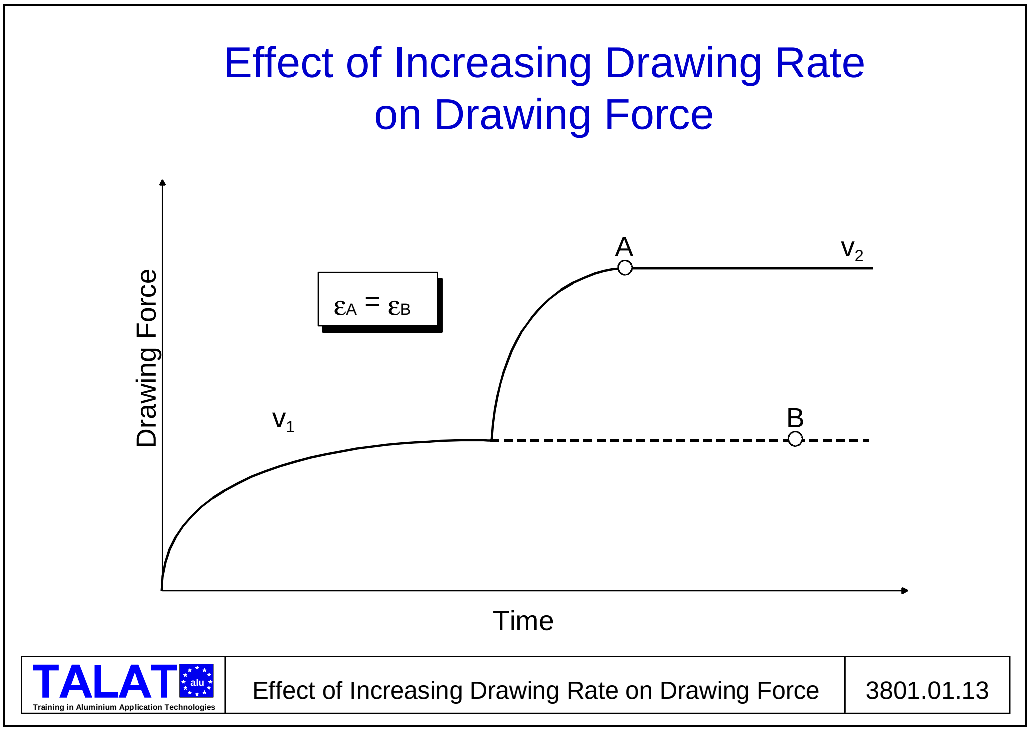


Besides the logarithmic strain rate $\dot{\varphi}$ the strain rate exponent *m* is the second value which governs the flow stress in the Ludwik equation. The strain rate exponent depends on various factors listed in **Figure 3801.01.12**. Each alloy has its own characteristic *m*-value behaviour. Other factors which play an important role are the average grain size, the forming temperature and the logarithmic strain.

A number of methods are available for measuring the rate exponent *m*. In principle, however, all these methods are based on the tensile test. **Figure 3801.01.13** schematically indicates the influence of a sudden increase in drawing rate on the measured drawing force. A specimen is elongated with a drawing rate of v_1 till a certain maximum stress is obtained, after which stationary flow begins. Once a defined specimen elongation is reached, the drawing rate is suddenly increased (or decreased) to the value v_2. The change ratio v_1/v_2 lies between 2 to 2,5. Due to the increase in straining rate, a different drawing force level is attained. The points *A* and *B* are locations with similar elongations of logarithmic strains, so that these can be related to each other. It is obvious, that the influence of the logarithmic strain is only of minor importance. In this manner, a measuring point $m = f(\varphi)$ can be determined for each tensile test. The force F_A is determined by extrapolating the load diagram for the rate v_1. According to *Backofen*, the rate exponent *m* can be calculated using the equation

$$m = \ln\left(\frac{F_A}{F_B}\right) / \ln\left(\frac{v_2}{v_1}\right)$$

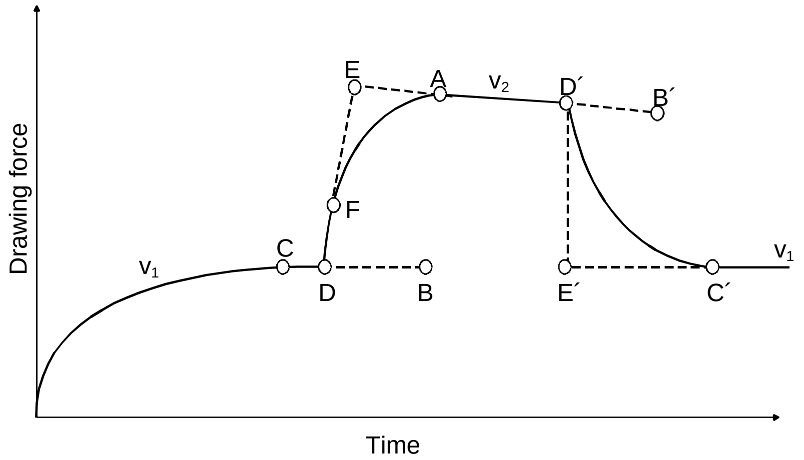




Methods of Determining the Strain Rate Exponent *m*

Further calculating methods for determining *m* have been developed in order to overcome the inaccuracy of the extrapolation method according to *Backofen* (see **Figure 3801.01.13**). The calculating points for the *m* values used in the various calculation methods are defined in the detailed force-time diagram, see **Figure 3801.01.14,** for sudden changes in the logarithmic strain rate from v_1 to v_2 or v_2 to v_1.

Methods of Determining the Rate Exponent m



TALAT Training in Aluminium Application Technologies | Methods of Determining the Rate Exponent m | 3801.01.14

Different Methods for Calculating the Rate Exponent m

According to MORRISON

$$m = \frac{\ln (k_{fA} / k_{fC})}{\ln (\dot{\varphi}_A / \dot{\varphi}_C)} \quad \text{or} \quad m = \frac{\ln (k_{fC'} / k_{fA})}{\ln (\dot{\varphi}_{C'} / \dot{\varphi}_A)}$$

According to HEDWORTH and STOWELL

$$m = \frac{\ln (F_{D'} / F_{E'})}{\ln (v_2 / v_1)} \quad \text{or} \quad m = \frac{\ln (F_E / F_D)}{\ln (v_2 / v_1)}$$

According to CUTLER

$$m = \frac{\ln (k_{fA} / k_{fD})}{\ln (\dot{\varphi}_2 / \dot{\varphi}_1)}$$

TALAT Training in Aluminium Application Technologies | Different Methods for Calculating the Rate Exponent | 3801.01.15

Based on **Figure 3801.01.14**, the equations for the individual calculation methods are shown in **Figure 3801.01.15**. According to *Morrison*, the *m* value is calculated as the quotient of the logarithmic ratios of the flow stresses at the points *A* and *C* and the local logarithmic strain rates. According to *Hedworth* and *Stowell*, *m* can be calculated from the logarithmic ratios of the force values determined at the points *D* and *E* and their drawing rates. It is assumed here that the specimen cross-section immediately before and after the sudden strain rate jump is the same. According to *Cutler*, the *m* value is calculated from the logarithmic ratio of the flow stresses at the points *A* and *D* and the average strain rate before and after the rate jump.

Factors Influencing the Strain Rate Exponent *m*

The *m* value is shown qualitatively as a function of the logarithmic strain rate $\dot{\varphi}$ in **Figure 3801.01.16**. The parameters are the forming temperature and the average grain size. Reducing grain size and increasing forming temperatures give more favourable *m* values.

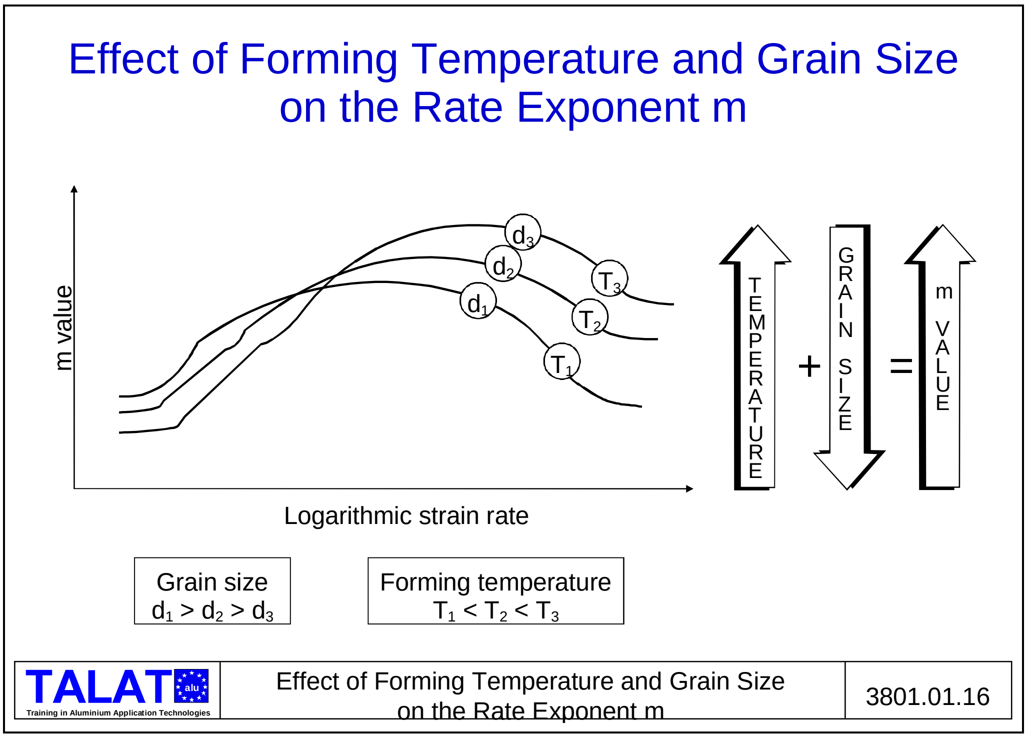


Figure 3801.01.17 shows the rate of cross-sectional area change *dA/dt* as a function of the cross-sectional area *A* for the *m* values of 1, 0.75, 0.5 and 0.25. For *m* = 1 (Newtonian flow), *dA/dt* is independent of *A*. Thus, an uncontrolled necking in the specimen cross-section does not occur even at high elongations and small specimen cross-sectional areas. The notch sensitivity of the specimen increases with decreasing *m* values. The effect of *m* on the flow resistance decreases, the logarithmic strain is locally concentrated and necking starts.

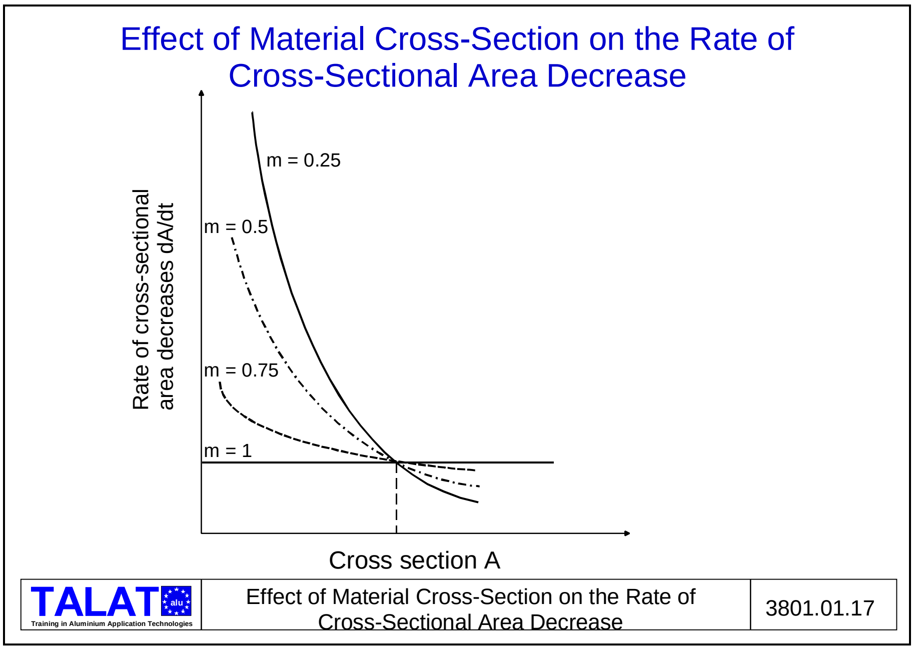


Figure 3801.01.18 clearly depicts the correlations between the *m* value, logarithmic strain rate and rupture elongation. The logarithmic strain rate has a very strong effect on flow stress in zone II. Both elongation at rupture and the *m* value also have their maxima in this zone. The zone I is rate insensitive, so that *m* and the attainable rupture elongation have their minimum values here. Similar conditions exist in zone III, i.e. low gradient of the flow stress curve with increasing strain rate. The *m* value also decreases in this zone. In summary, superplastic forming behaviour does only occur in the region of the rate zone II.

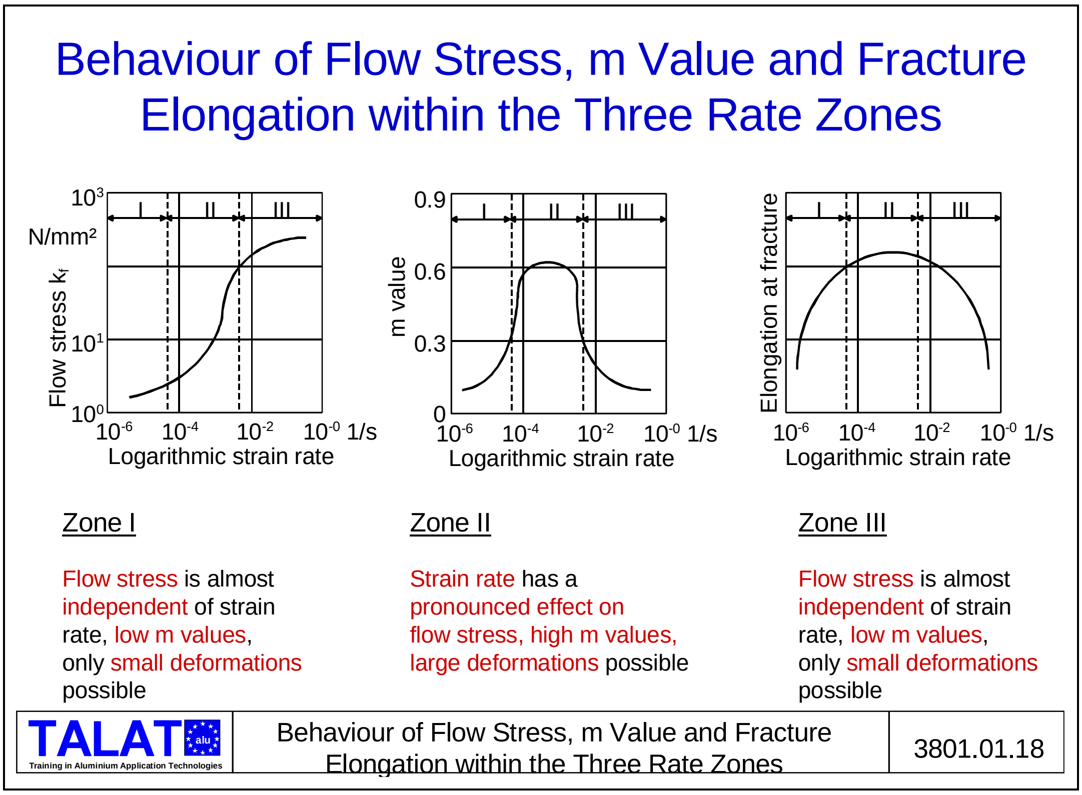
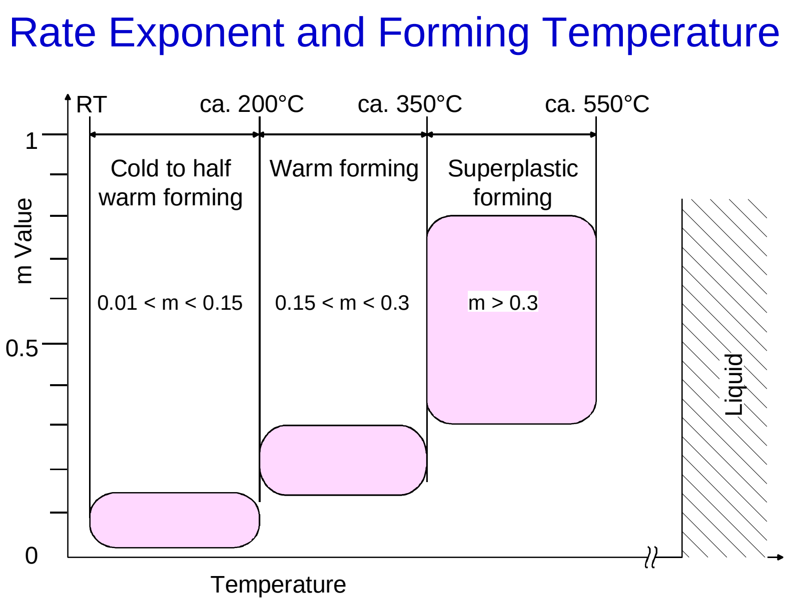


Figure 3801.01.19 lists the *m* values obtained from literature for different forming temperature ranges. It is to be noted here, that the flow stress is almost independent of the strain rate at room temperature and increases with increasing temperature. The maximum values for *m* are obtained in the temperature range for superplastic forming.



TALAT	Rate Exponent and Forming Temperature	3801.01.19

List of Figures