TALAT Lecture 3702

Tribology in Cold Forming of Aluminium Sheet

13 pages, 12 figures

Basic Level

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Objectives:

- to appreciate the importance of friction in sheet metal drawing
- to describe the mechanism of friction and lubrication
- to show the importance of surface topography
- to learn about factors improving the problem of adhesion and about
- methods of determining the coefficients of friction in different tribological systems

Prerequisites:

- background in production engineering and sheet metal forming
- TALAT Lecture 3701

Date of Issue: 1996

3702 Tribology in Cold Forming of Aluminium Sheet

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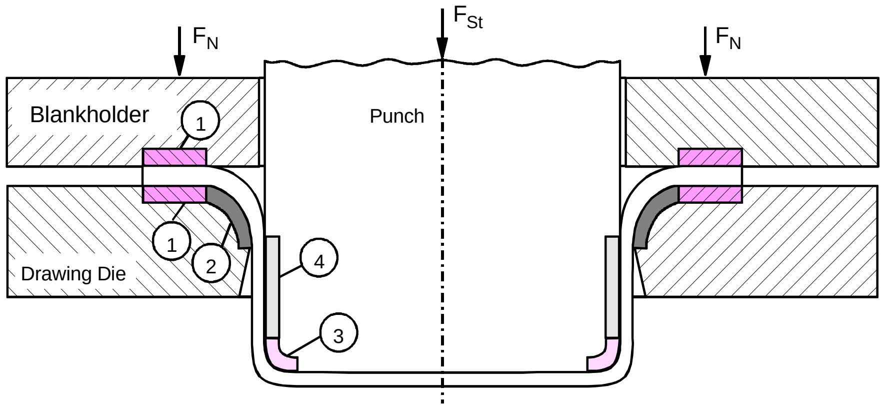
3702.01 Friction in Deep Drawing and Drawing of Car Body Parts

Apart from the formability of sheet materials the tribological conditions in the contact zones between the sheet surface and the tool surface play an important part in determining the procedural limits of the forming process. Friction in the various contact zones affects the flow of the material in the tool and is used deliberately to control the forming process.

The friction zones in deep drawing and in drawing of car body parts are illustrated schematically in **Figure 3702.01.01** and **Figure 3702.01.02**, respectively. The demands made on the friction situation in these friction zones can vary greatly depending on the type of part being drawn and on the forming procedure. In deep drawing, low friction is required under the blankholder (zone 1) and at the drawing die curvature (zone 2), in order to reduce drawing forces. At the punch edge (zone 3), friction needs to be as high as possible, so that high forces are introduced into the cup wall at the transition zone from punch to cup wall. If special areas have to be drawn out by stretch forming in the bottom of the drawn part, low friction values are desirable at the punch face (zone 4). To control material flow in the case of irregular drawn parts, such as, e.g. car body parts, higher friction may be necessary in certain parts of the blankholder, which can be achieved with locally higher surface pressure or with braking bulges (draw beads).

Friction Zones in Deep Drawing



Friction zones:

① Drawing die and blankholder

② Drawing die curvature

③ Punch edges

④ Punch-shank surface

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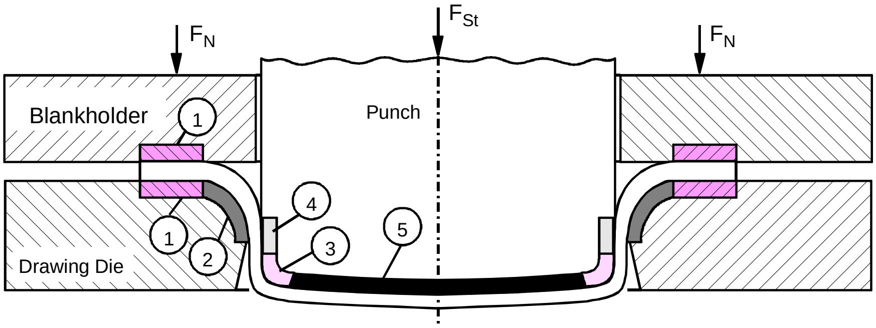
Friction Zones in Drawing of Car Body Parts



Friction zones:

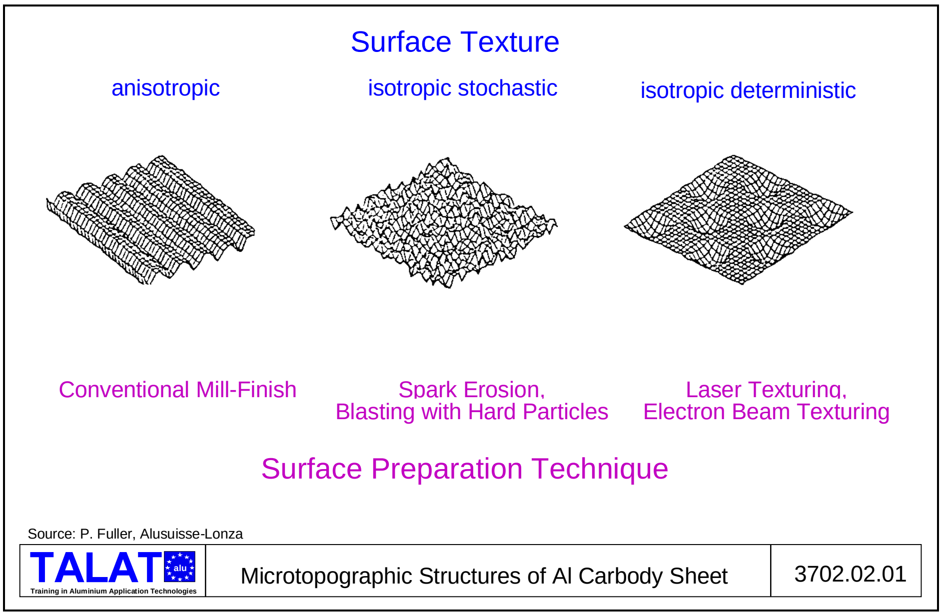
① Drawing die and blankholder
② Drawing die curvature
③ Punch edges
④ Punch-shank surface
⑤ Punch face

TALAT Training in Aluminium Application Technologies | Friction Zones in Drawing of Car Body Parts | 3702.01.02

3702.02 The Effects of Microtopography of the Sheet Metal Surface

The tribological system as a whole consists of the sheet surface, the tool surface and the lubricant. The lubricant prevents abrasion and wear of the tool and workpiece surfaces, and, particularly in the case of drawn aluminium parts, prevents adhesion at the tool surface. Lubrication is, therefore, vital to the drawing of parts from bare aluminium. At the same time, it is necessary to keep the use of lubricants as low as possible, since they have to be removed after forming prior to any further operations such as joining or surface treatment. The capacity of the sheet surface to absorb lubricant and thus the precise surface microtopography of the sheet are correspondingly important.

The standard rolled surface of aluminium sheet is the so-called “mill-finish“ surface with relatively low roughness coefficients. It is produced with tangentially ground rolls and thus exhibits a directional roughness, which produces different tribological behaviour parallel and transverse to the rolling direction. The topographic image of the mill-finish surface is depicted in **Figure 3702.02.01**. Lubricant contained in the long stretched roughness valleys will be squeezed or drained out under the force of the die pressure before a significant hydrostatic pressure can build up. Such surfaces are, therefore, rather prone to adhesion and abrasion during forming operations and exhibit directionality in the coefficient of friction and with regard to the tendency of adhesion, as will be seen later.



Surface Texture

anisotropic	isotropic stochastic	isotropic deterministic
Conventional Mill-Finish	Spark Erosion, Blasting with Hard Particles	Laser Texturing, Electron Beam Texturing

Surface Preparation Technique

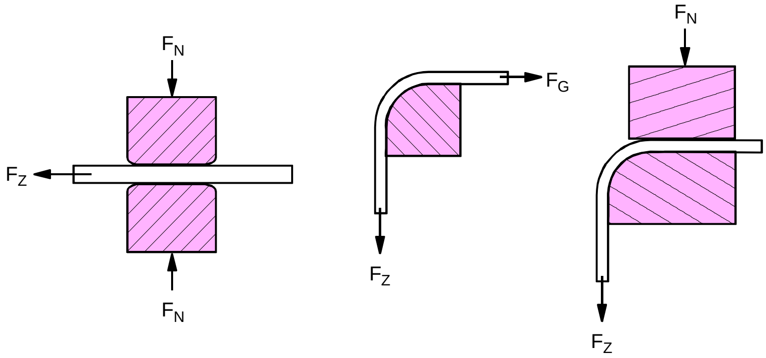
Source: P. Fuller, Alusuisse-Lonza

TALAT Training in Aluminium Application Technologies | Microtopographic Structures of Al Carbody Sheet | 3702.02.01

The anisotropy of the friction performance of the mill-finish surface can be overcome by the use of roll surfaces prepared by blasting, electro-discharge or laser texturing. The resultant isotropic structures of the surface microtopography is also shown in **Figure 3702.02.01**. These surface structures are characterised by closed pits which entrap the lubricant. Flattening of the rims due to contact with the tool surface builds up hydrostatic pressure in the entrapped lubricant, which helps to reduce the danger of adhesion.

To model the friction behaviour and to study the various tribological effects and parameters a number of special tests have been developed, see **Figure 3702.02.02**. Most of these tests methods incorporate friction tests on sheet specimen strips, which are drawn between a mock die and blankholder. Blankholder pressure and drawing force can be monitored individually and the resulting friction coefficient can be measured. Friction strip tests can be performed with and without simulating the drawing over a die curvature.

Measuring Friction with Strip Drawing Tests



Strip drawing without bending

Strip drawing with bending

F_Z Drawing force
F_G Reaction force
F_N Blankholder force

Source: Wojtowicz / Littlewood and Wallace / Woska

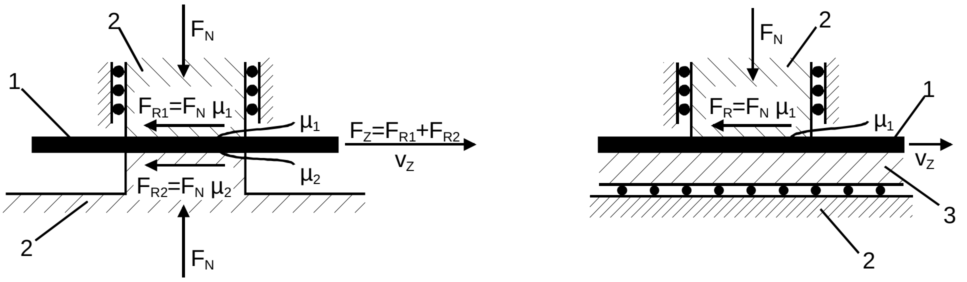
TALAT Training in Aluminium Application Technologies | Strip Drawing Tests | 3702.02.02

Figure 3702.02.03 shows two friction strip testing methods without bending actions. In the test set-up (a) the strip is drawn between two stationary dies, measuring an average of the friction coefficients on both sides of the strip. As sheet qualities become available, which have different surface treatments on either side of the sheet, it may be necessary to determine the friction behaviour separately for both sides of the sheet. The test set-up (b) employs a tool sled, which is moved on frictionless air bearings (cf. Institut für Umformtechnik, Universität Stuttgart).

Forces and Friction Coefficients in Strip Drawing Friction Tests

a) double-sided friction

b) single-sided friction



$F_R=F_Z=F_N\ (\mu_1+\mu_2)$

$F_R=F_N\ \mu_1$

1 Sheet strips
2 Gripping (drawing) jaws
3 Drawing sledge (air bearings)

Source: IfU - Stuttgart

TALAT Training in Aluminium Application Technologies | Forces and Friction Coefficients in Strip Drawing Tests | 3702.02.03

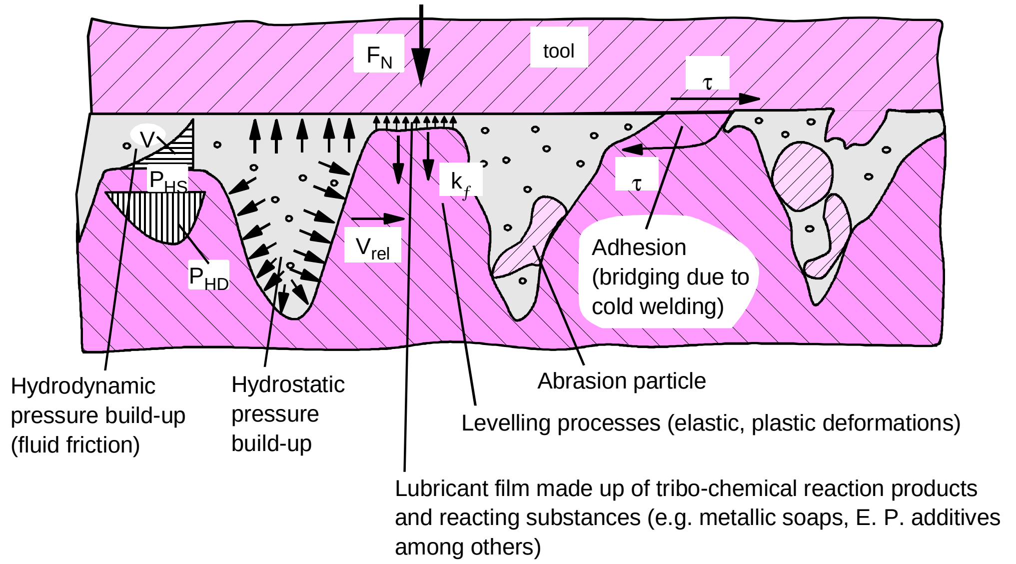
3702.03 Mechanism of Friction

The tribological conditions in sheet metal forming operations are characterised by rather low relative velocities between work piece and die surfaces, by generally low pressures in the macroscopic contact area between die and sheet metal and by relatively large areas of macroscopic contact between die and work piece surfaces. Under these conditions liquid or pasty lubricants can be employed to reduce the frictional forces between dry metal surfaces. The low relative velocities do not provide conditions for general hydrodynamic lubrication.

On a microscopic scale, however, there are zones between the die and work piece surfaces separated by a thin layer of lubricant and zones of direct metallic contact. The magnitude of metallic contact depends on a number of factors, among which the surface roughness and its microtopological structure as well as the amount of lubricant are the most important ones.

When the die surface meets the generally rougher and softer surface of the sheet metal the area of direct metallic contact is at the first instant relatively small and restricted to a few roughness peaks. Due to the high specific local pressure the peaks are flattened and the die surface sinks deeper into the sheet surface. The lubricant enclosed in the roughness valleys builds up a hydrostatic pressure and transmits the die pressure onto the sheet metal surface. At the same time the excess lubricant is driven out of the valleys, forced between the flattened roughness peaks and forms a thin boundary film made up of tribo-chemical reaction products and reacting substances (e.g., metallic soaps, E., P. additives among others). This situation is depicted in **Figure 3702.03.01**.

Mechanism of Friction



$(\mu_{liquid} + \mu_{interface} + \mu_{solid}) = \mu_{total} = f\,(t,s,v,....)$

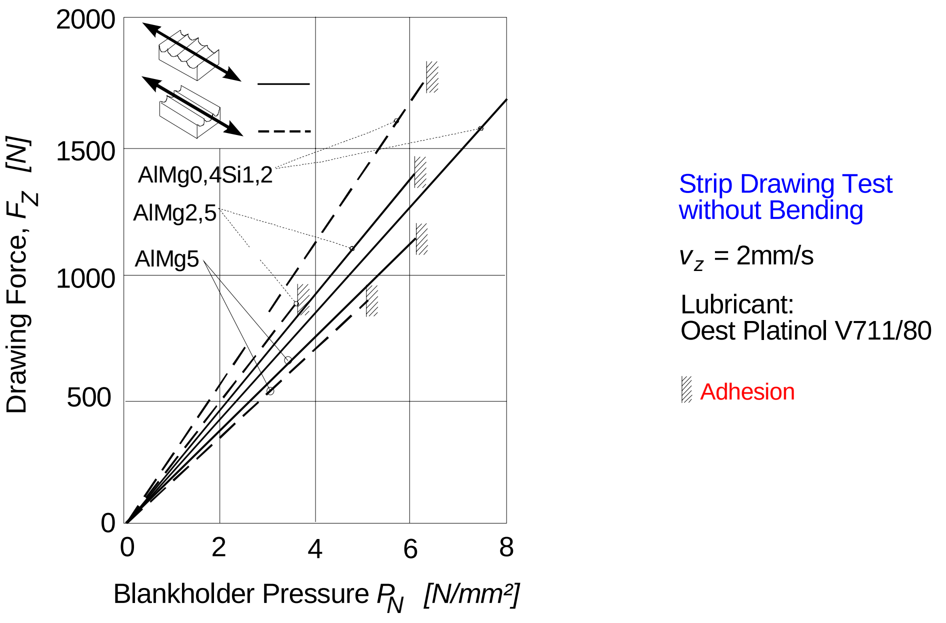
Source: IfU - Stuttgart

TALAT Training in Aluminium Application Technologies	Mechanism of Friction	3702.03.01

The relative motion during the drawing operation builds up shear stresses in the flattened peak zones. If the boundary layer ruptures due to motion or high die pressure the metallic surfaces get into direct metallic contact. The result will be adhesion due to local pressure welding. These metallic bridges rupture during further motion, partly sticking to the die surface and partly breaking loose as abraded particles. At this stage lubrication has broken down.

3702.04 Effect of Surface Properties on Friction Behaviour

The friction and adhesion behaviour of aluminium car body sheet materials have been determined using the strip friction test method without bending. For standard mill-finish surfaces the results are shown in **Figure 3702.04.01**. (The tests were carried out using a drawing speed of 2 mm/sec, a drawing distance of 100 mm and lubricant Oest Platinol V711/80). The effect of the directionality of the surface roughness becomes apparent with respect to the point of seizure and to the friction coefficient.



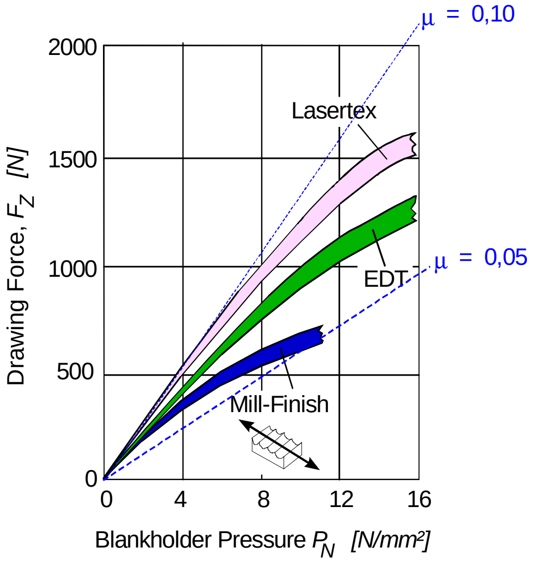
Source: E. Mössle, 1983

Friction Behaviour of Al Carbody Sheet
in Strip Drawing Tests

3702.04.01

From **Figure 3702.04.02** it is evident that the isotropic surfaces, such as „Lasertex“ or „EDT“, perform much better with regard to seizing and galling. Good results are also achieved with roll surfaces prepared by blasting. (The tool material was cast iron GG25CrMo, drawing speed 100 mm/sec, drawing distance 370 mm and lubricant mineral oil M100).

Figure 3702.04.03 exhibits the friction and adhesion behaviour of aluminium car body sheet with surface treatments prepared by coil coating. While Cr^{VI}-conversion coatings have little beneficial influence on adhesion when compared with the bare metal surface, the organic coatings prove superior in this respect.



AlMg0,4Si1,2-T4

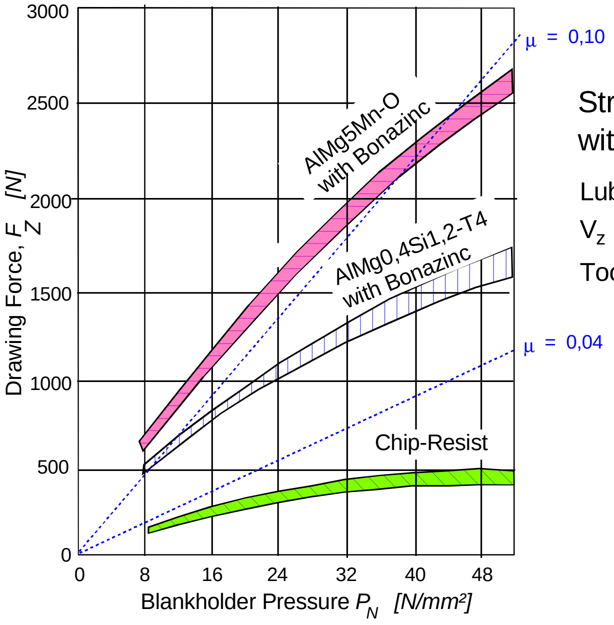
Lubricant: M100

V_z = 100 mm/s

Tool: X155CrVMo121

Source: S. Wagner, IfU, Universität Stuttgart, 1994

TALAT Training in Aluminium Application Technologies	Effects of Microtopographic Structure on Friction Properties	3702.04.02



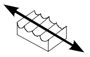
Strip Drawing Friction Test without Bending

Lubricant: M100

V_z = 100 mm/s

Tool: 1.2379

Mill-Finish



Source: S. Wagner, IfU, Universität Stuttgart, 1994

TALAT Training in Aluminium Application Technologies	Friction Properties of Coil Coated Aluminium	3702.04.03

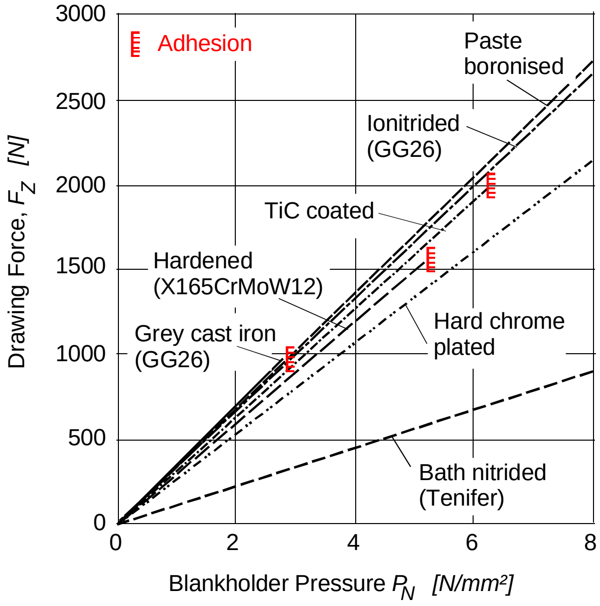
3702.05 The Tool Surface

The second friction partner in the tribological system, the tool surface also makes an important contribution to the tribological situation. Basically the same tool materials are used for drawing aluminium body parts as for manufacturing steel bodies, for example cast iron GG26, GG25CrMo and tool steel inserts for drawing edges, drawing beads and cutting edges. To prevent the occurrence of adhesion, the roughness of the tool surface in critical contact zones should meet the following requirements

$R_z \leq 1\ \mu m$
$\lambda_p \geq 0{,}46$

where
R_z = average peak-to-valley depth
λ_p = degree of profile emptiness = R_p/R_t
R_p = peak to mean line height
R_t = peak to valley height

The adhesion tendency and the friction behaviour can be particularly effectively influenced by surface treatment of the tool, as shown in **Figure 3702.05.01**. The type of surface treatment which is particularly suitable for a specific case depends on the technical and economical parameters, such as the type of tool material and the size of the tool.



Strip Drawing Test without Bending

AlMg0.4Si1.2-T4

v_z = 2mm/s

Lubricant:
Oest Platinol V711/80

Source: E. Mössle, 1983

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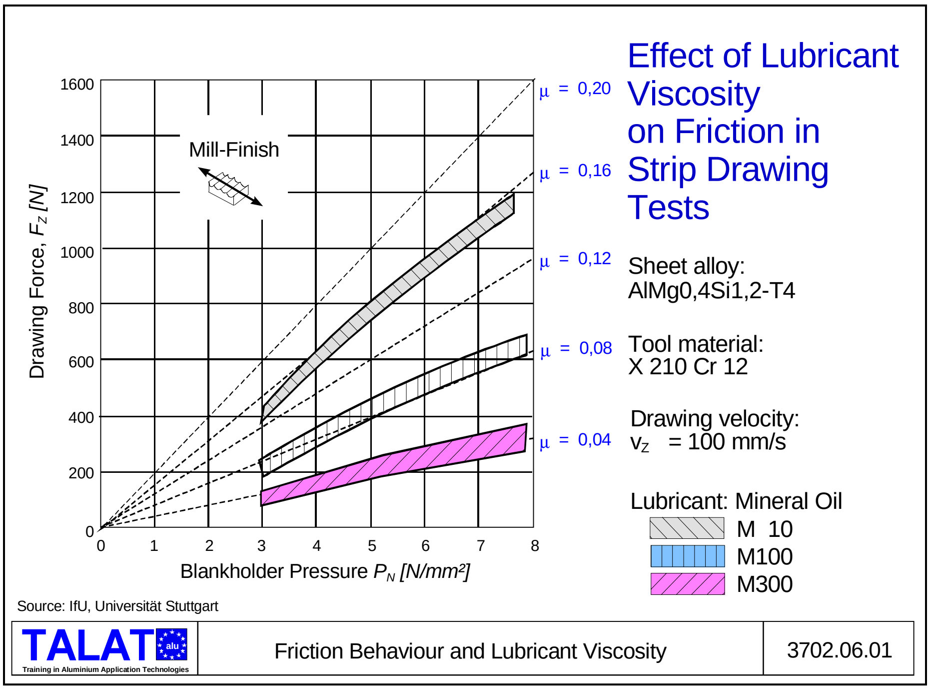
Effects of Tool Surface Treatments on Friction and Adhesion of Aluminium Carbody Sheet

3702.05.01

3702.06 Lubrication

The third tribological partner is the lubricant. Successful drawing of aluminium body parts depends decisively on the choice of a lubricant and its application to the sheet blank and the tool. Greasing of the sheet blank is generally performed by roll application today. In particular cases it may be necessary to use pressure lubrication in specific areas of the tool itself.

There is a large selection of lubricants available today. One important factor in the choice of the lubricant is the dynamic viscosity. **Figure 3702.06.01** shows the influence of the dynamic viscosity on the friction coefficient as tested with unalloyed mineral oil M10, M100 and M300, the numbers corresponding roughly with the dynamic viscosity η (in 10^{-3} Ns/m^2) at room temperature. The higher the viscosity the lower is the friction coefficient.



Effect of Lubricant Viscosity on Friction in Strip Drawing Tests

Sheet alloy:
AlMg0,4Si1,2-T4

Tool material:
X 210 Cr 12

Drawing velocity:
v_Z = 100 mm/s

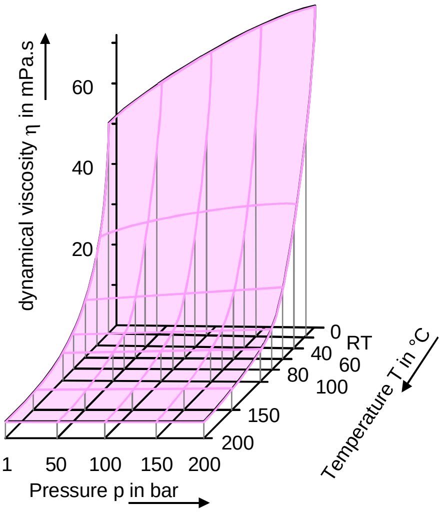
Lubricant: Mineral Oil
▨ M 10
▥ M100
▨ M300

Source: IfU, Universität Stuttgart

TALAT	Friction Behaviour and Lubricant Viscosity	3702.06.01

It is important also to realize that the viscosity of lubricants can vary significantly with temperature. **Figure 3702.06.02** shows the pressure and temperature dependence of an alloyed lubricant (Oest Al2N). The lubricant exhibits a steep reduction in dynamic viscosity with temperature increasing slightly above room temperature. Temperature rises have been measured at the drawing die radius in the order of 10 to 15 °C. In critical areas this temperature rise and the resulting decrease in dynamic viscosity must be taken into account.

Dynamic viscosity behaviour of a compounded lubricant



Source: IfU - Stuttgart

TALAT Training in Aluminium Application Technologies | Temperature and Pressure Dependence of the Dynamic Viscosity of Lubricants (Oest AL2N) | 3702.06.02

3702.07 Literature/References

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