

**TALAT Lecture 4701**

**Adhesive Bonding -  
Terms and Definitions**

20 pages, 24 figures

Basic Level

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**Objectives:**

- to define the terms and definition of adhesive bonding of metals
- to describe the basic physical/chemical characteristics of adhesive bonding
- to describe the characteristics and the properties of adhesives used in metal bonding

**Prerequisites:**

- general background in production engineering and material science
- background in the physics and chemistry of metallic surfaces and polymer science

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# 4701 Terms and Definitions for Adhesive Bonding

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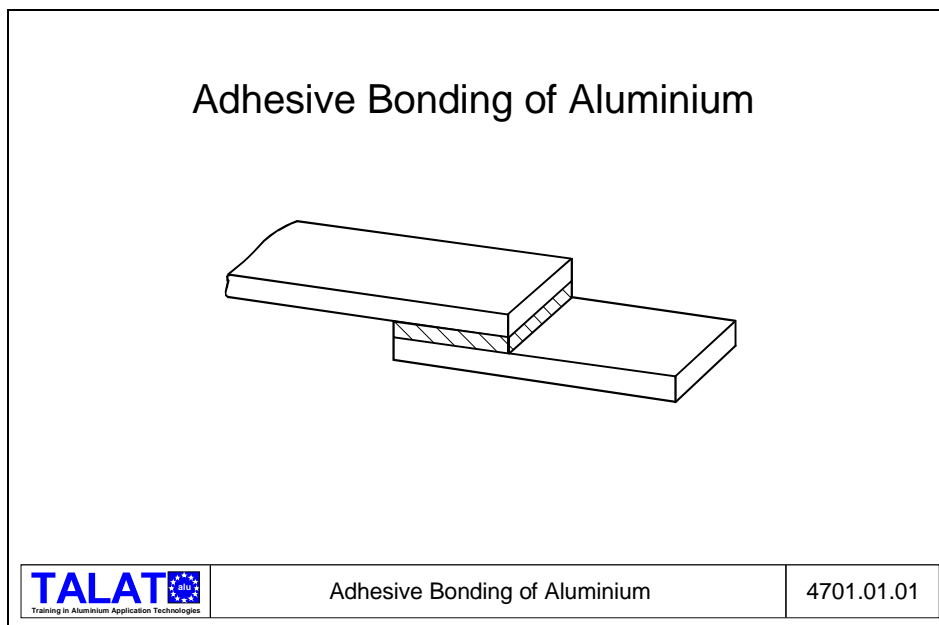
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## 4701.01 Definition and Application of Adhesive Bonding

- Adhesive bonding of aluminium
- Classification of adhesive bonding
- Load distribution of joints
- Advantages and disadvantages of adhesive joining
- Structure of an adhesive joint
- Adhesion and cohesion
- Mechanism of deposition of macromolecules on surfaces
- Bond types in adhesive joints
- Bond forces in adhesive joints (dipole bonds)
- Bond forces in adhesive joints (hydrogen bonds)
- Failure of adhesive joints

### Adhesive bonding of aluminium

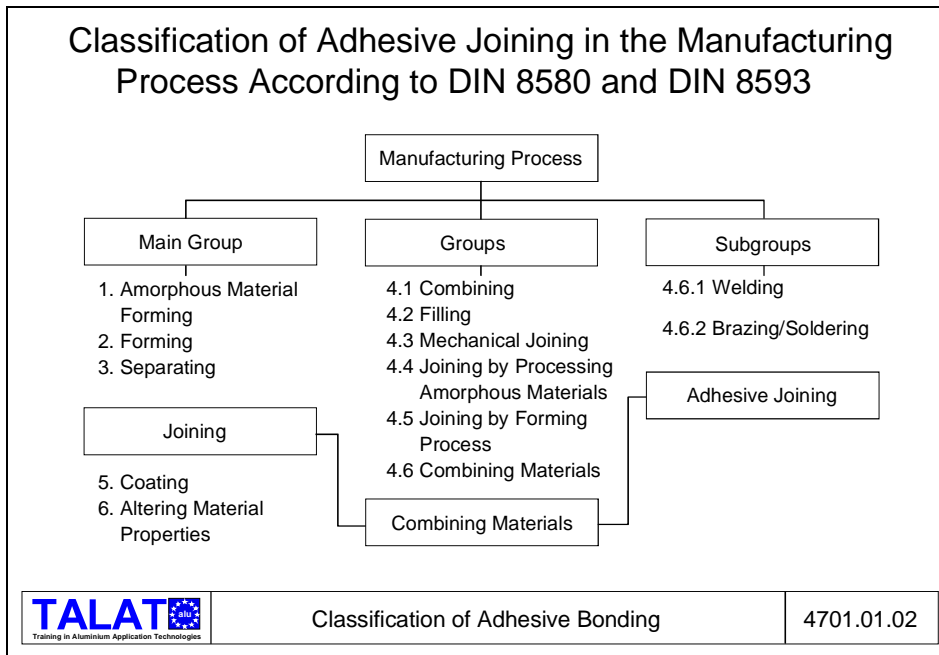
Adhesive joining is defined as the process of joining parts using a non-metallic substance (adhesive) which undergoes a physical or chemical hardening reaction causing the parts to join together through surface adherence (adhesion) and internal strength (cohesion) (**Figure 4701.01.01**).



### Classification of adhesive bonding

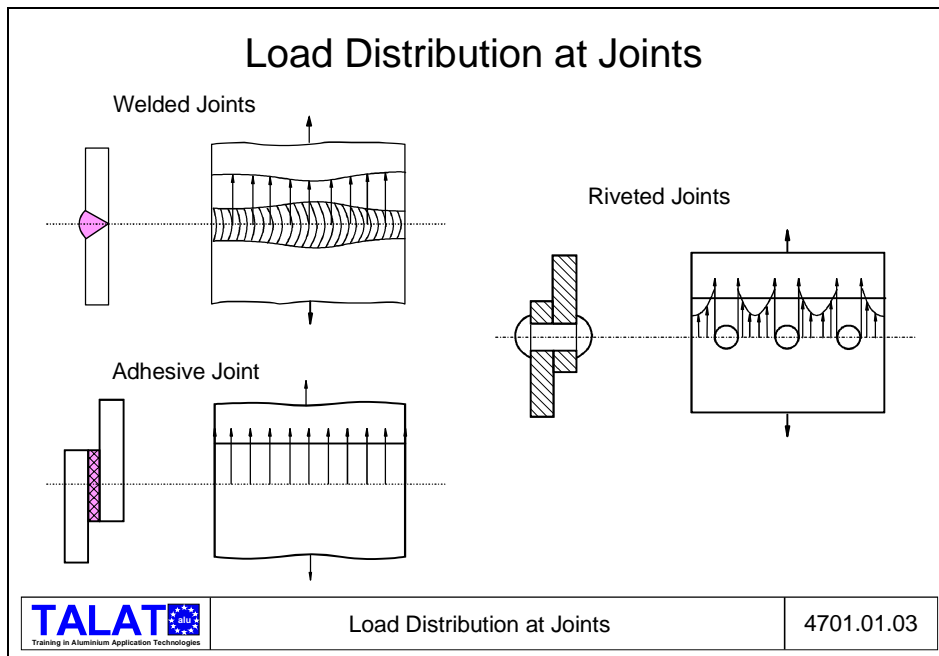
In the German standards DIN 8580 and 8593, adhesive joining is classified within the manufacturing processes in the main group joining, the group combination of substances and the subgroup adhesive joining, together with welding and brazing/soldering (**Figure 4701.01.02**).

## Classification of Adhesive Joining in the Manufacturing Process According to DIN 8580 and DIN 8593



### Load distribution of joints

The main advantage of adhesive joining over welding, riveting, brazing and screw fastening is that the load is distributed more evenly at right angles to the loading direction (**Figure 4701.01.03**). In the direction of the loading itself, however, this is valid only for scarfed adhesive joints.




### Advantages and disadvantages of adhesive joining

It must be remarked that all the different joining processes are not generally competitive and should rather be considered as being complementary.

The appropriate joining technology for any application should be chosen on the basis of

its technological and/or economical superiority.

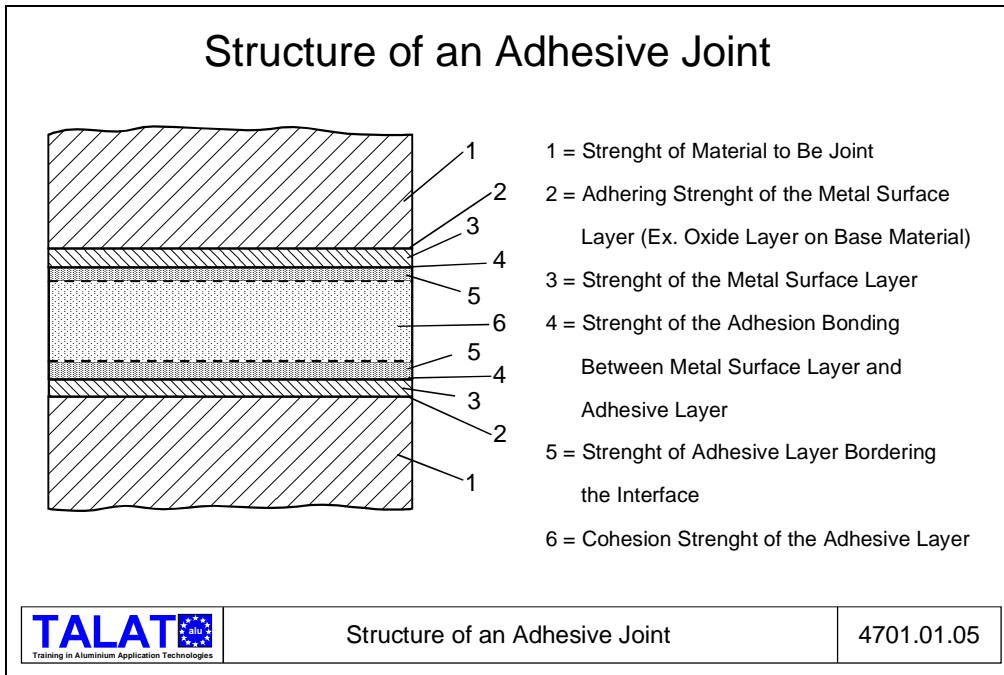
The list showing the advantages and disadvantages of adhesive joining serves as a help in choosing the appropriate joining method (**Figure 4701.01.04**).

Advantages	Disadvantages	
<ol style="list-style-type: none"><li>1. Load distributed uniformly at right angles to loading direction</li><li>2. Microstructure unaffected</li><li>3. Distortion-free joining</li><li>4. Different materials can be joined</li><li>5. Very thin parts can be joined</li><li>6. Weight saving, light constructions</li><li>7. Heat-sensitive materials can be joined</li><li>8. Metals with different electrochemical properties can be joined (insulating effect of adhesive)</li><li>9. High strength in combination with riveting, spot welding screw-fastenings (eliminates crack corrosion)</li><li>10. High fatigue strength, good vibration damping</li></ol>	<ol style="list-style-type: none"><li>1. Influence of time on process properties</li><li>2. Pretreatment of joining parts surfaces</li><li>3. Limited form stability</li><li>4. Process parameters must be held within very narrow range; low tolerance</li><li>5. Change of properties of joint with time (ageing of adhesive layer etc.)</li><li>6. Complicated control of process</li><li>7. Low peeling strength, creep sensitive</li><li>8. Low adhesive layer strength must be compensated by large joining area</li><li>9. Repair possibilities limited</li><li>10. Complicated strength calculation</li></ol>	
Source: Habenicht		
	Advantages and Disadvantages of Adhesive Joining	4701.01.04

### Structure of an adhesive joint

Adhesive joints are composite systems whose strength depends on both the geometrical design and loading type as well as on the schematically illustrated individual strengths of the components to be joined, the adhesive and the interface layer.

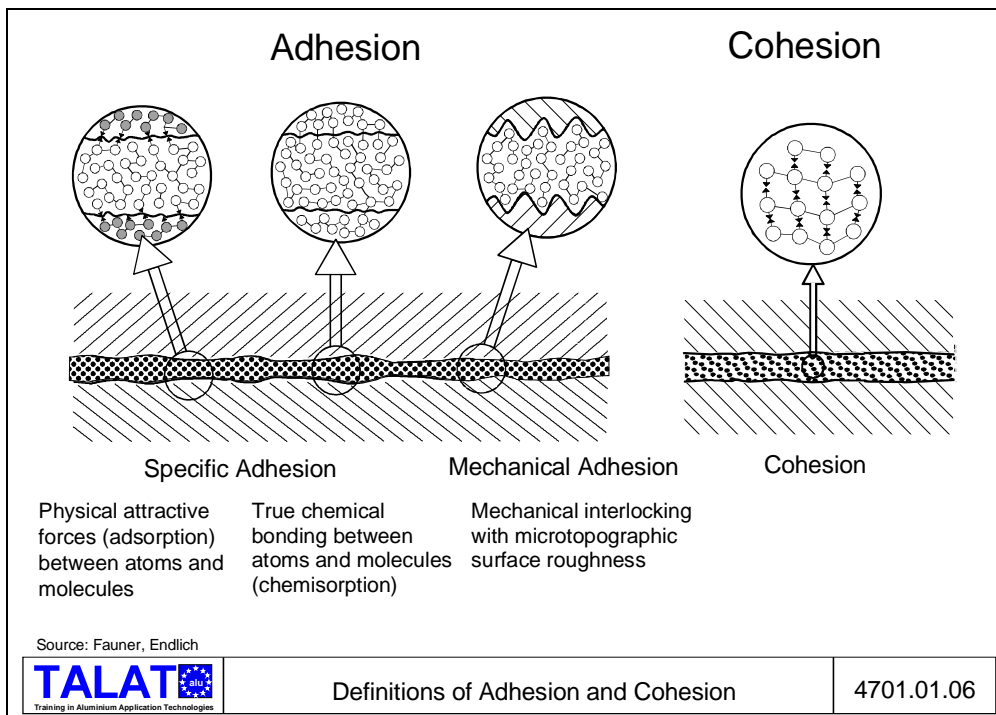
As in every composite system consisting of different members, the overall strength is limited by the weakest member (**Figure 4701.01.05**).



### Adhesion and cohesion

Adhesion is defined as the adhesive force acting between the adhesive and the surface of the material. This force is the result of the mechanical interlocking between adhesive and the material surface roughness (mechanical adhesion) as well as the physical and/or chemical interaction between the adhesive and the material (specific adhesion).

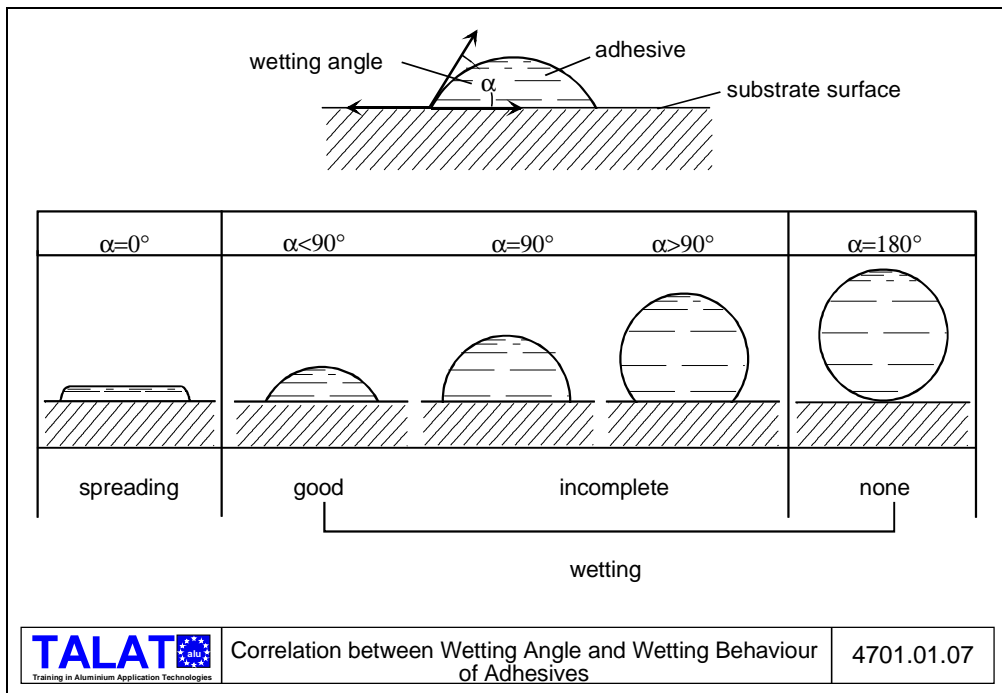
Cohesion is the strength of the adhesive itself. This is a result of the mechanical entangling and interlocking of the adhesive molecules and their physical and/or chemical affinity for each other (**Figure 4701.01.06**).



A necessary condition for attaining high adhesion forces is the ability of the adhesive to wet the surfaces of the joining parts properly.

The wetting is optimal when the angle of contact  $\alpha$  does not exceed  $30^\circ$  (**Figure 4701.01.07**). This can be achieved, in principle, by a suitable surface treatment of the joining parts and by choosing an appropriate viscosity for the adhesive.

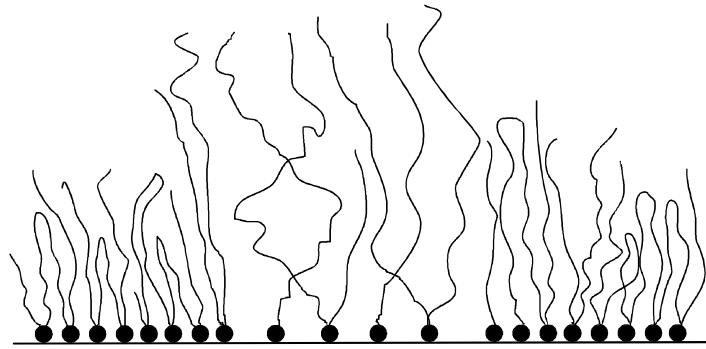
Macromolecules, and consequently adhesives also, are adsorbed point-wise and as loops on the solid surfaces.



### Mechanism of deposition of macromolecules on surfaces

During hardening, the parts of the molecular chains which are not adsorbed, form the solid adhesive layer due to the formation of intermolecular forces (main and/or secondary valency forces (**Figure 4701.01.08**). Among the chemical bond types, the homopolar bonds (atomic bonds, non-polar bonds, covalent bonds) are the deciding factors for the manufacturing and wetting capacity of adhesives (formation of main valency bonds). The metallic bond is important for the formation of high adhesion forces through chemisorption.

## Mechanism of Deposition of Macromolecules on Surfaces



Deposition Mechanism of Macromolecules on Surfaces

Source: Jenkel, Rumbach



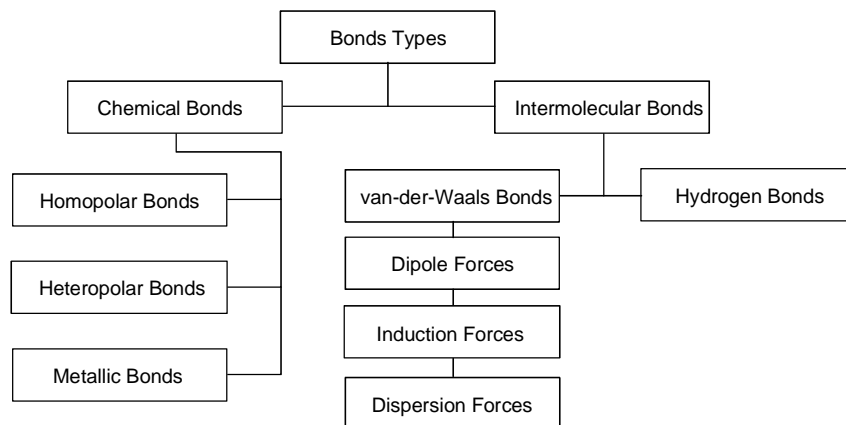
Mechanism of Deposition of Macromolecules on Surfaces

4701.01.08

### Bond types in adhesive joints

The intermolecular bonds (secondary valency bonds) act between the adhesive molecules as well as between adhesive and the surfaces of the joining parts and are thus relevant for the cohesion and adhesion strength (**Figure 4701.01.09**).

### Bond Types in Adhesive Joints



Source: Habenicht



Bonds Types in Adhesive Joints

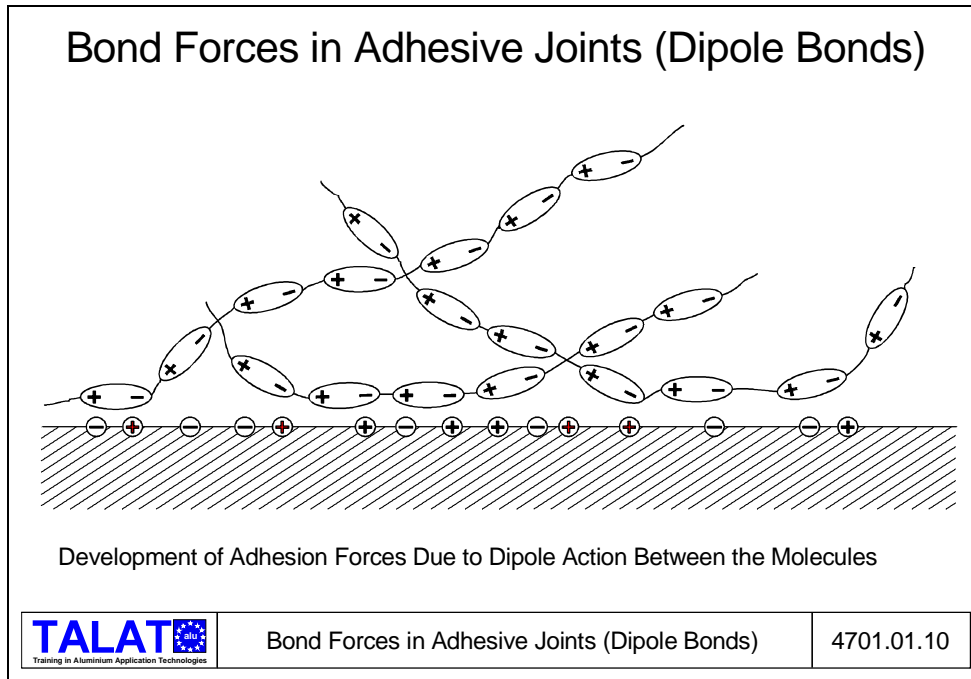
4701.01.09

### Bond forces in adhesive joints (dipole bonds)

Numerous adhesives contain polar molecule groups (dipoles) which have a strong polarising action on the metallic joining parts, the latter being non-polar in themselves. The dipole forces can operate effectively only if these molecule groups can approach to

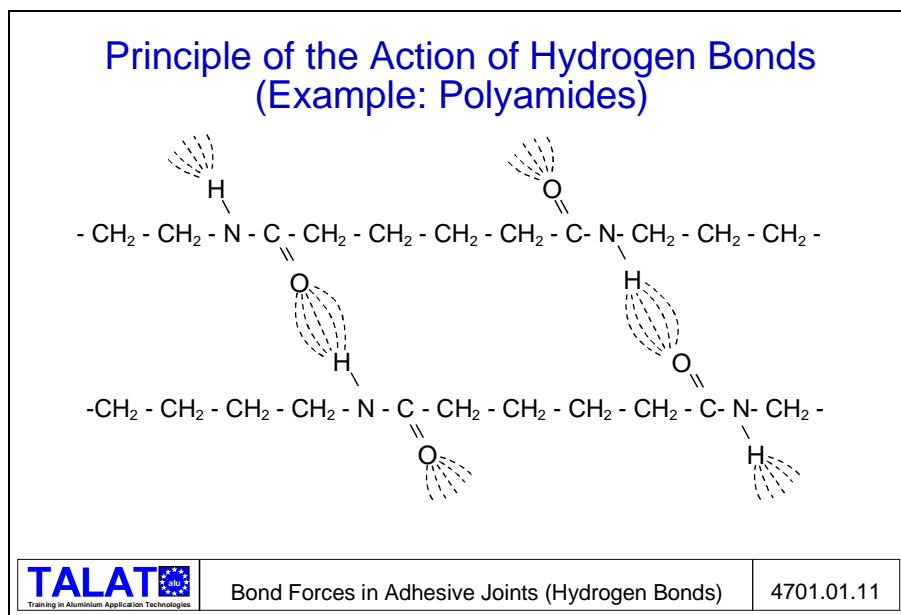


within about 0.1 mm of the surface of the joining parts (**Figure 4701.01.10**). The above is only possible if the adhesive can wet the solid surfaces optimally.



### Bond forces in adhesive joints (hydrogen bonds)

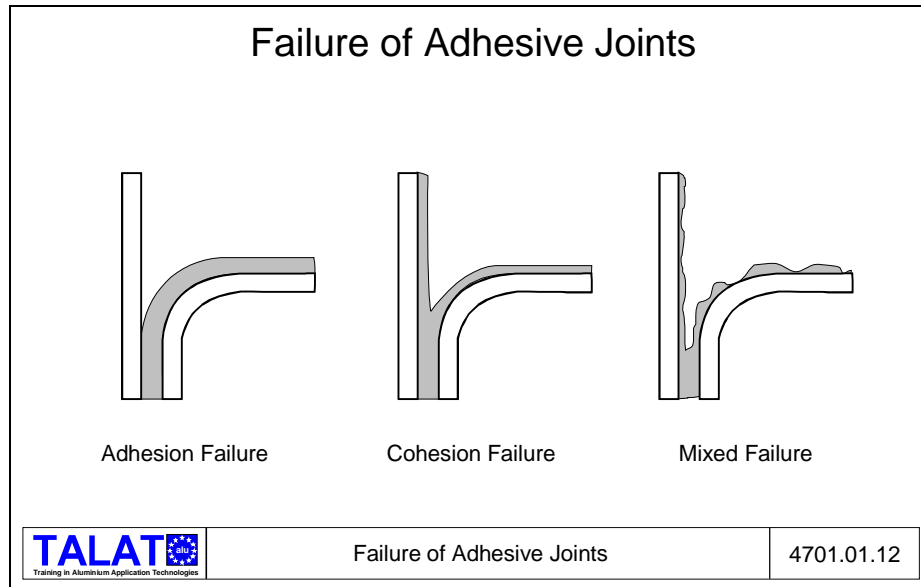
Hydrogen bonds are a special form of intermolecular bonds. These are, for example, responsible for the relatively high cohesion strengths of PUR and PA adhesives (**Figure 4701.01.11**).



Hydrogen bonds can also be formed between adhesives and solid surfaces when the latter are oxidised or contain adsorbed hydrogen molecules.

## Failure of adhesive joints

The separation of adhesive joints occurs due to the failure of adhesion or cohesion or of both (i.e., mixed adhesion and cohesion failure) (**Figure 4701.01.12**).



A cohesion failure is to be strived at. An adhesion failure indicates that the surfaces of the parts to be joint had not been properly pretreated.

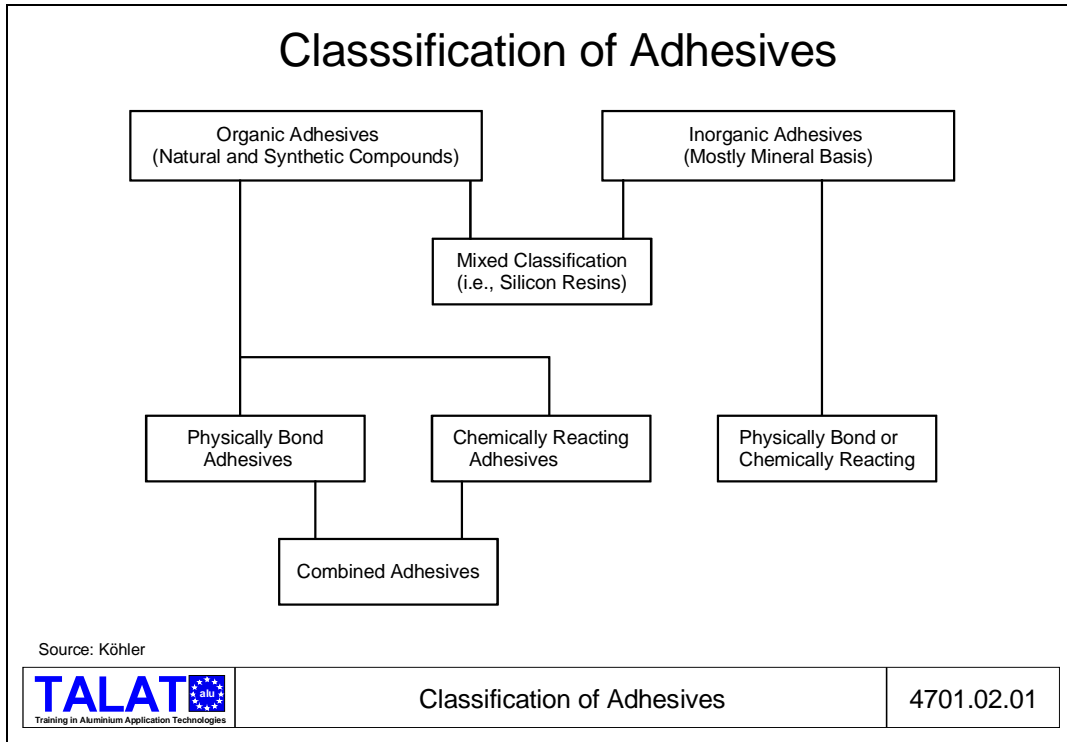
## 4701.02 Classification, Characteristics and Properties of Adhesives

- Classification of adhesives
- Physically bonding adhesives
- Chemically reacting adhesives
- Classification of adhesives according to forming reaction and polymer structure
- Structure of adhesives
- Properties of diuromeres
- Properties of amorphous thermoplastics
- Properties of partly crystalline thermoplastics
- Stress-strain curve of AlCuMg<sub>2</sub> and an epoxy resin adhesive
- Creep properties of adhesive layers
- Variation of creep strength with temperature
- Temperature stability of different adhesive basis

### Classification of adhesives

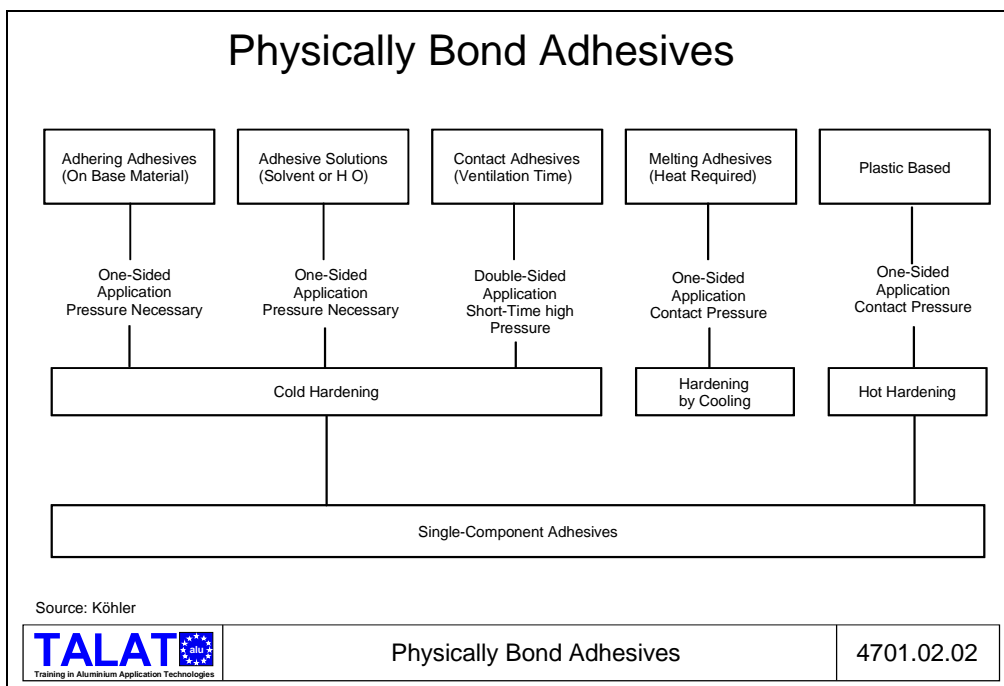
In principle, all the listed adhesives can be used for joining metals, albeit with different results and performances.

Organic ceramic adhesives are a special case of adhesives which have to be hardened at high temperatures, deliver relatively low strengths but can withstand high operating temperatures (**Figure 4701.02.01**).



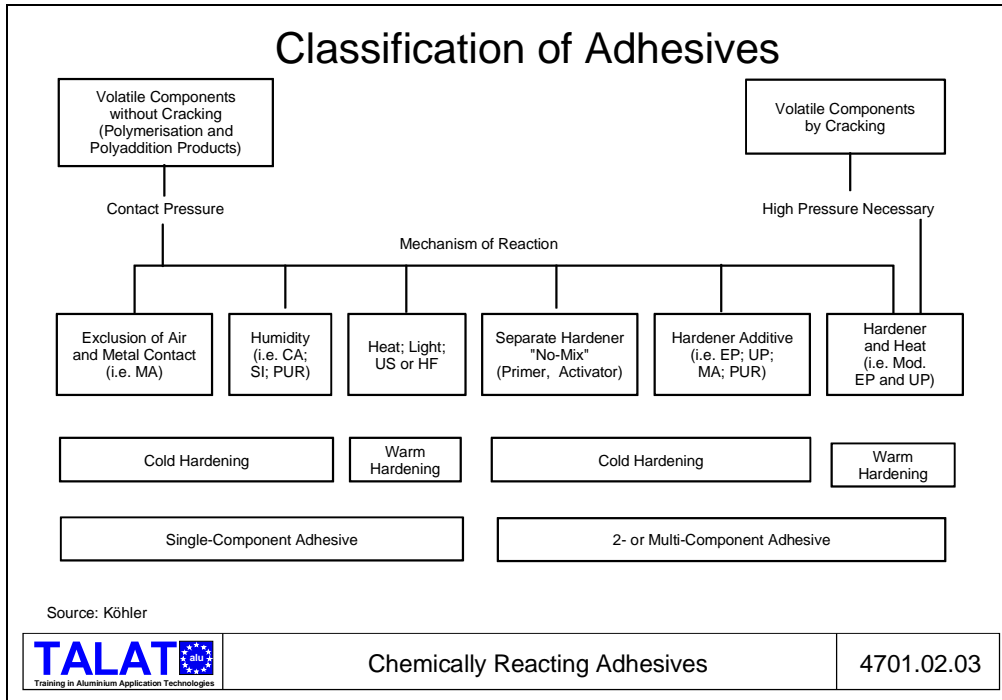
### Physically bonding adhesives

Pressure sensitive adhesives and melting adhesives of the physically bonding types can be used efficiently and should receive, therefore, special consideration (**Figure 4701.02.02**).



## Chemically reacting adhesives

Chemically reacting adhesives of the synthetic organic type are, for example, phenolic resins (PR), epoxy resins (ER), unsaturated polyester resins (UP), polyurethanes (PUR), cyanoacrylates (CA) and methylacrylates (MA) (**Figure 4701.02.03**).

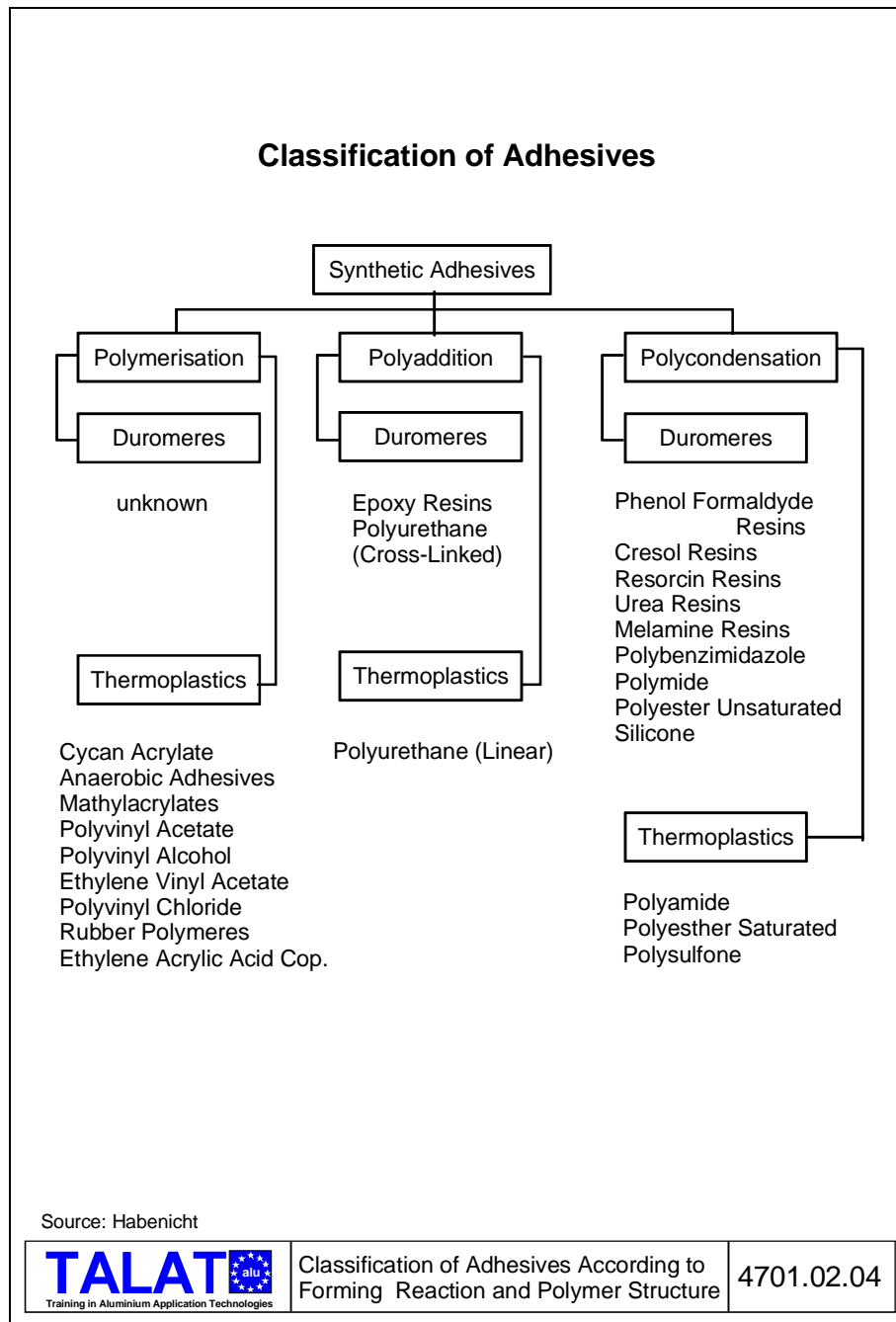


## Classification of adhesives according to forming reaction and polymer structure

Polymerisation is an exothermic process in which monomers link together to form macromolecules by the breaking of the double bonds of the C atoms, without cracking to by-products. Thermoplastics are produced exclusively.

During polycondensation, water is the most common by-product produced. Both thermoplastics as well as thermosetting plastics are produced.

During polyaddition, the water atoms are only rearranged. Even here, thermoplastics as well as thermosetting plastics are produced (**Figure 4701.02.04**).

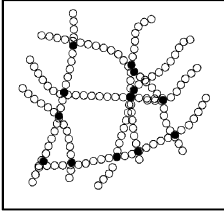


## Structure of adhesives

Thermosetting plastics - The basic molecules cross-link across a number of free main valencies to a spatial molecule structure. This results in high strengths and rigidities.

Thermoplastics have a linear molecular structure (string-like macromolecules). A large number of molecule strings are held together by physical secondary valency bonds. Amorphous thermoplastics have a "cotton wool" structure. In semi-crystalline thermoplastics, parts of the microstructure depict a definite structural arrangement so that the attractive forces in these regions are more intensive than in the amorphous areas (**Figure 4701.02.05**).

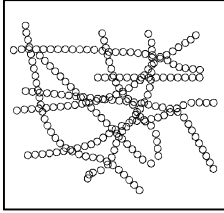
### Structure of Adhesives



**Duromere**

Cross-Linked Molecules

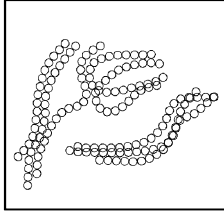
Amorphous



**Thermoplastic**

String Molecules

Amorphous




**Thermoplastic**

String Molecules

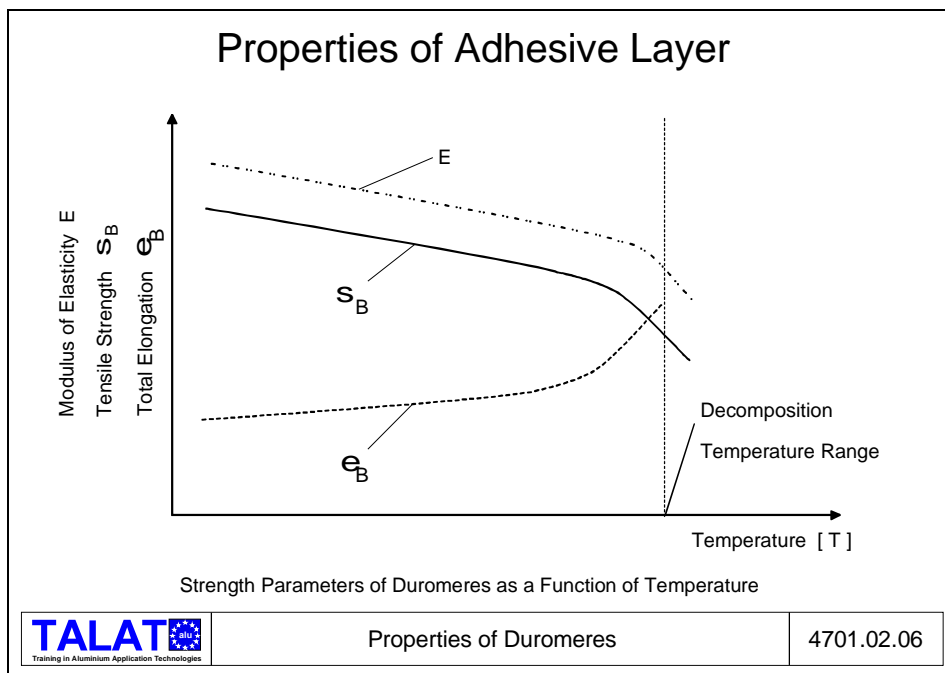
Partly Crystalline

Construction of Polymer Structures of Monomers

Source: Habenicht

	Structure of Adhesives	4701.02.05
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### Properties of duromeres

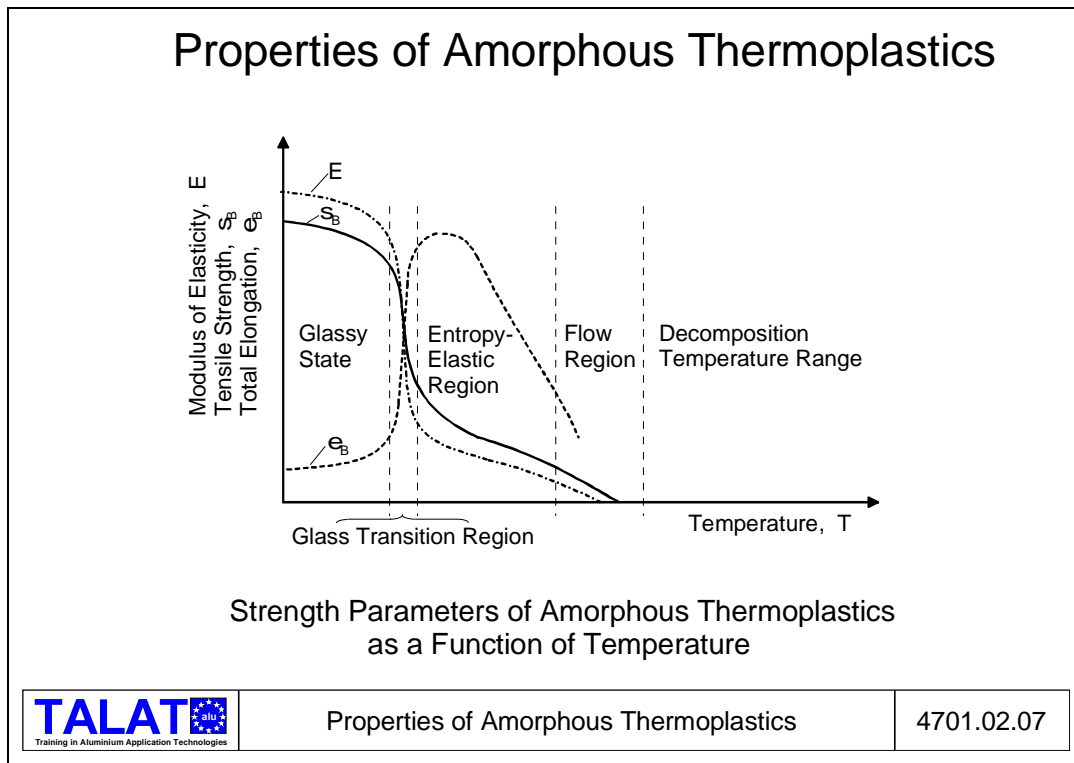


With increasing temperature up to the decomposition temperature, the tensile strength and modulus of elasticity of the thermosetting plastics fall only slightly but the elongation increases somewhat (**Figure 4701.02.06**).

### Properties of amorphous thermoplastics

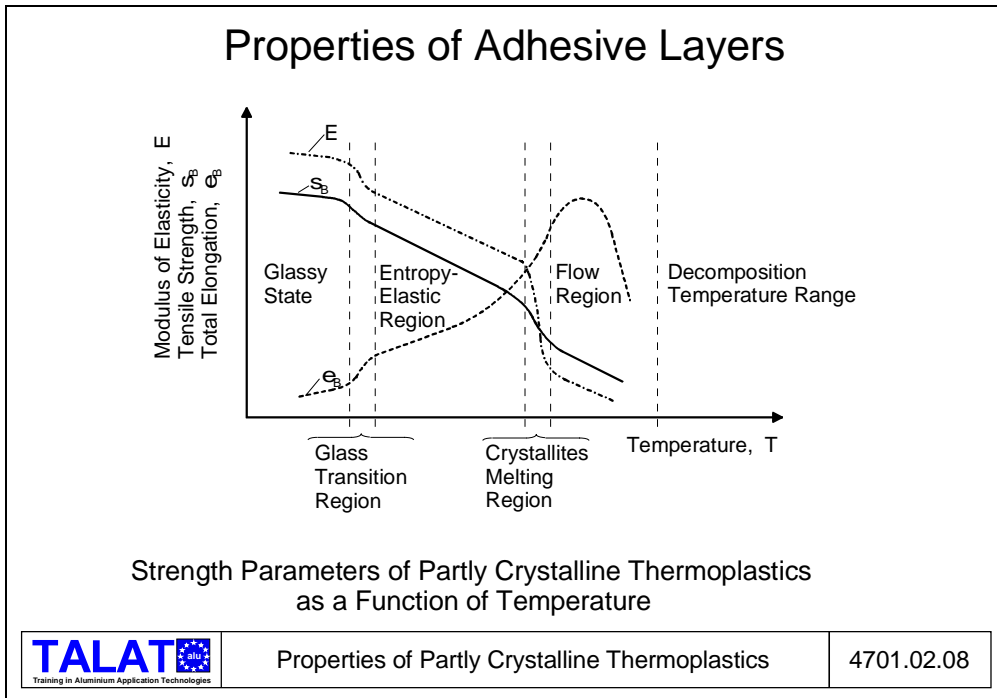
With increasing temperature, the tensile strength and modulus of elasticity of the thermoplastics fall almost uniformly with the elongation increasing at the same time. On

reaching the glass-transition-temperature region, there is a rapid fall in tensile strength accompanied by a sudden increase in elongation. A further increase in temperature leads to a maximum in elongation, with the strength approaching zero. Increasing the temperature further causes the elongation to fall (**Figure 4701.02.07**).



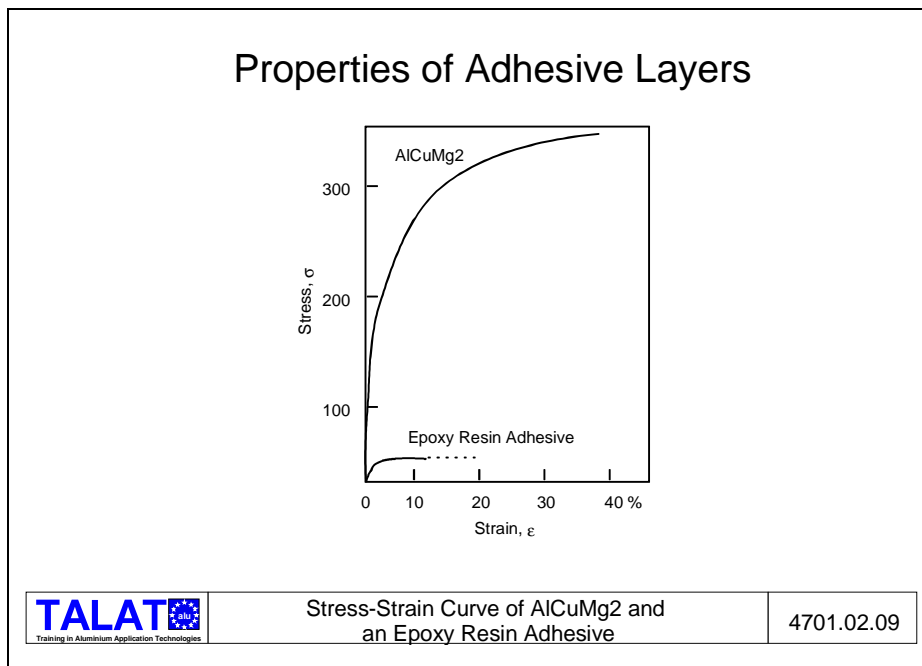
### Properties of partly crystalline thermoplastics

The glass-transition-temperature region, which in the case of amorphous thermoplastics is higher than the practical operational temperature, lies by about 0 °C for the semi-crystalline thermoplastics. At the melting region of the crystals, these thermoplastics lose their form. This is the reason for the higher modulus of elasticity and the insensitivity of the semi-crystalline thermoplastics to impact loadings (**Figure 4701.02.08**).



### Stress-strain curve of AlCuMg<sub>2</sub> and an epoxy resin adhesive

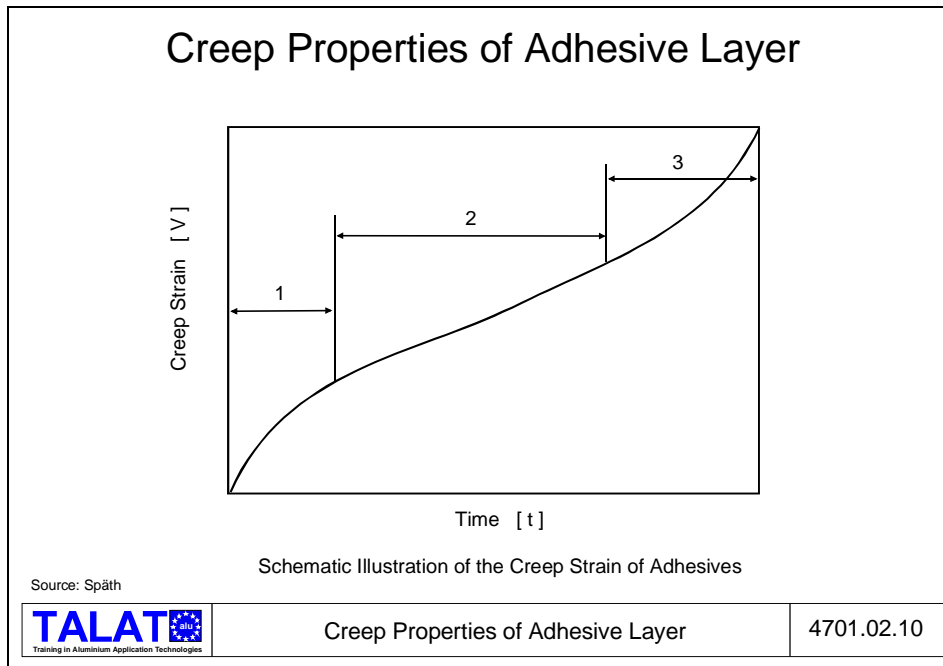
Adhesives exhibit a deformation behaviour very different to that of the metallic parts being joined. Although the material AlCuMg<sub>2</sub> still behaves elastically up to tensile stresses of about 200 N/mm<sup>2</sup> due to its modulus of elasticity, the linear correlation between stress and strain is valid for only a very narrow region for the adhesive layer. Characteristic for most polymers is the fact that the major part of the stress-strain curve is non-linear and that the individual polymers exhibit very different stress-strain behaviours among themselves (**Figure 4701.02.09**).





## Creep properties of adhesive layers

The tendency of adhesives to creep is the main factor governing the time-temperature behaviour of the adhesive joint. Creep can be defined as the time-dependent increase in length of viscoelastic substances subject to a constant tensile load, whereby an asymptotical load-dependent limiting value of elongation is reached.

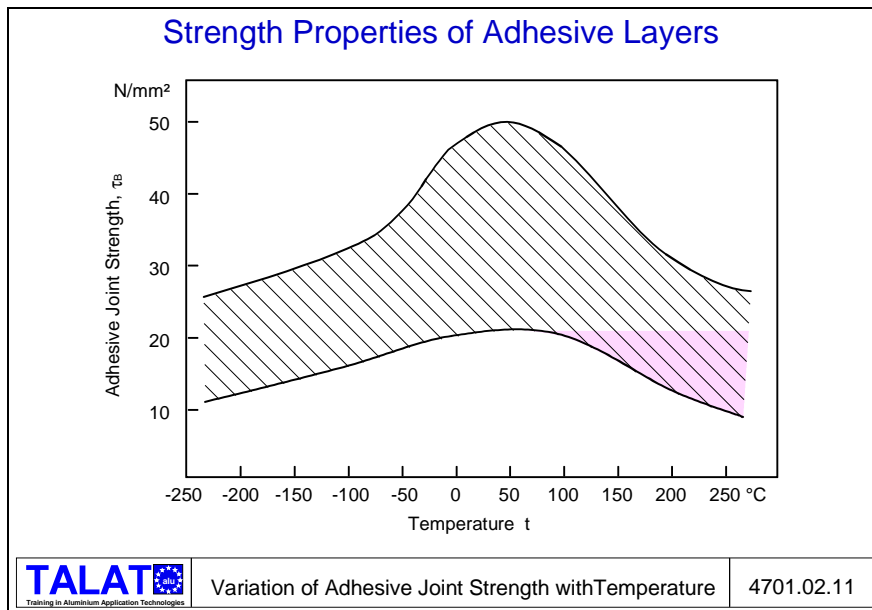


A typical creep curve exhibits 3 stages of creep (**Figure 4701.02.10**):

- Primary (transient) creep: - elastic deformation of molecules - rupture of secondary valency bonds and rearrangement of linked-chain segments - no plastic deformation.
- Secondary (stationary) creep: - constant creep rate - equilibrium between the competing processes of rupture and creation of new bonds within the molecule aggregate.
- Tertiary (accelerated) creep: - rupture of adhesive joint initiated - deformation limit of adhesive layer reached.

### Variation of creep strength with temperature

The hardened adhesive layers of the best-known base substances (i.e., phenolic resins, epoxy resins, epoxy nylons, polyurethane) exhibit a strength behaviour within large regions of temperatures similar to the one shown in **Figure 4701.02.11**.



At low temperatures, the strength of the adhesive layer rises only slightly with temperature (glassy state) until the strength reaches a peak value which, depending on the structure, can extend over a large temperature range. Due to the increased plasticity of the adhesive layer, stress peaks occurring at the ends of the overlaps can be reduced. At still higher temperatures a flow and decomposition process sets in, causing the strength of the adhesive layer to fall.

### Temperature stability of different adhesive basis

The values given in **Figure 4701.02.12** are the maximum upper temperature ranges for the operating condition. These can, however, only serve as rough estimates for limiting values under operating conditions. Special modifications can be used to attain still higher limiting values.

Properties of Adhesives	
Adhesive Base	Temperature Range °C
Epoxy Dicyanodiamide ( Warm Hardening )	110 ... 130
Epoxy Polyamide ( Cold Hardening )	60 ... 90
Phenolic Resins ( Warm Hardening )	80 ... 120
Polymethyl Methylacrylate ( Cold Hardening )	80 ... 100
Polyurethanes	80 ... 100
Polyester	60 ... 80
Cyanoacrylate	70 ... 80
Polydiacrylacidester ( Anaerobic Hardening )	120 ... 150
Polyamides	120 ... 140
Polyimide	200 ... 300
RTV - Silicones	180 ... 190

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Temperature Stability of Different Adhesive Basis

### 4701.03 Literature/References

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