Products – Forged products

Table of contents

4 Forged products

4.1 Characteristics of automotive forgings

See also:

- AAM – Applications – 2 Chassis > Wheels > Forged wheels
- AAM – Materials – 5 Wrought materials productions > Forging

Aluminium forgings are used to save weight of components which require

- high functional durability,
- high structural integrity,
- high fatigue resistance, and
- high toughness and ductility.

Aluminium forgings in **automotive applications** are, therefore, generally chosen for components which are essential for the safety of the vehicle:

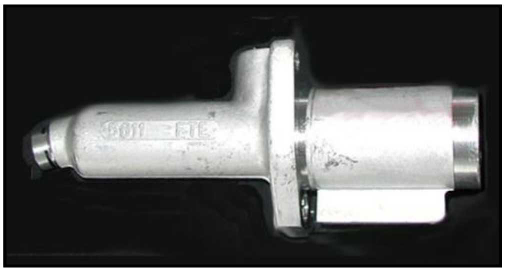
- system components of front and rear axles: e.g. control arms, knuckles, wheels,
- components of the brake system: e.g. caliper, hydraulic system components.

Concentric slave cylinder, alloy EN AW-6082-T6

Source: FTE

Clutch slave cylinder, alloy EN AW-6082-T6

Source: FTE



Clutch master cylinder, alloy EN AW-6082-T6

Source: FTE

Coupling, BMW-3

Source: Otto-Fuchs Metallwerke

Couplings for drive shaft, alloy 6082-T6

Source: Otto-Fuchs Metallwerke

Control arm, alloy 6082-T6

Source: Otto-Fuchs Metallwerke

Control arm, alloy 6082-T6

Source: Otto-Fuchs Metallwerke

Control arm, alloy 6082-T6

Source: Otto-Fuchs MW

Control arm, alloy 6082-T6

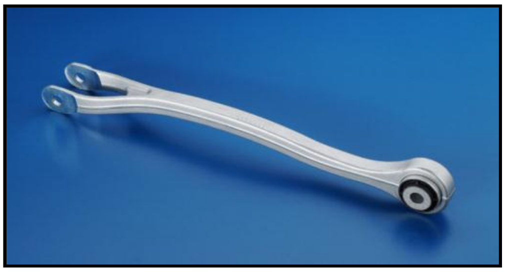
Source: Otto-Fuchs Metallwerke

Control arm, alloy 6082-/6

Source: Otto-Fuchs Metallwerke

Control arm, alloy 6082-T6

Source: Otto-Fuchs Metallwerke



Control arm, alloy 6082-T6

Source: Otto-Fuchs Metallwerke

4.2 Alloys

4.2.1 Forging alloys – Compositions

While in principle all wrought aluminium alloys can be die or hand forged, only a limited selection of alloys is commonly used. The preferred alloys (s. EN 586-2) include:

Non-age-hardening alloys:
EN AW-5754-H112 (AlMg3)
EN AW-5083-H112 (AlMg4.5Mn0.7)

Age-hardening alloys:
EN AW-2014-T6 (AlCu4SiMg)
EN AW-2024-T4 (AlCu4Mg1)
EN AW-6082-T6 (AlSi1MgMn)
EN AW-7075-T6, -T73 (AlZn5.5MgCu)

For reasons of strength, age-hardening alloys are used for structural applications. Due to its excellent corrosion resistance alloy **EN AW-6082-T6** is almost exclusively used for automotive **suspension** and **chassis components**.

Composition of alloy EN AW-6082:

Element	Weight-%
Si	0.7 - 1.3
Fe	0.50
Cu	0.10
Mn	0.40 - 1.0
Mg	0.6 - 1.2
Cr	0.25
Zn	0.20
Pb	0.003 max.
Ti	0.10
Others	0.05 (single), 0.15 (total)
Al	Rest

4.3 Tempers and mechanical properties

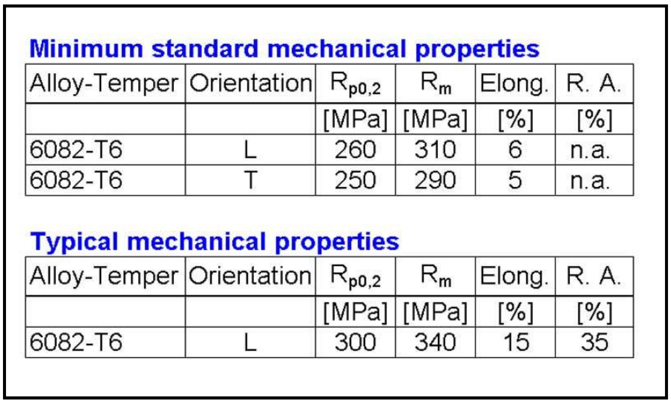
4.3.1 Static properties

See also:
- AAM – Materials – 4 Microstructure and properties
- AAM – Materials – 2 Alloy constitution > Heat treatment > Solution treatment and ageing > Special ageing effects in 6xxx alloys: stabilised T4 tempers (T4*)

(see also chapters "Fatigue" and "Crashworthiness")

After hot forming, age-hardening alloys such as EN AW-6082 exhibit the as-fabricated F-temper with no specified mechanical property limits. Special control of the thermomechanical processing conditions may be used to ensure defined property levels. Optimum characteristics are achieved subsequently by a complete heat treatment cycle (solution heat treatment incl. quenching and age-hardening).

In particular, if the heat treatment is carried out continuously within the production line, the obtained strength levels are significantly higher than the minimum standard values (s. table below). In a batch process with good process control similarly high values above minimum standards can also be achieved. The reason for this improvement of strength is the avoidance of room temperature ageing between quenching and artificial ageing.



Minimum standard mechanical properties

Alloy-Temper	Orientation	$R_{p0,2}$	R_m	Elong.	R. A.
		[MPa]	[MPa]	[%]	[%]
6082-T6	L	260	310	6	n.a.
6082-T6	T	250	290	5	n.a.

Typical mechanical properties

Alloy-Temper	Orientation	$R_{p0,2}$	R_m	Elong.	R. A.
		[MPa]	[MPa]	[%]	[%]
6082-T6	L	300	340	15	35

Note:
"L" denotes properties in direction of fibres
"T" denotes properties transverse to fibre direction

4.4 Corrosion resistance

4.4.1 General and intercrystalline corrosion and fatigue of pre-corroded alloy 6082-T6

See also:

- AAM – Products – 2 Extruded products > Corrosion resistance

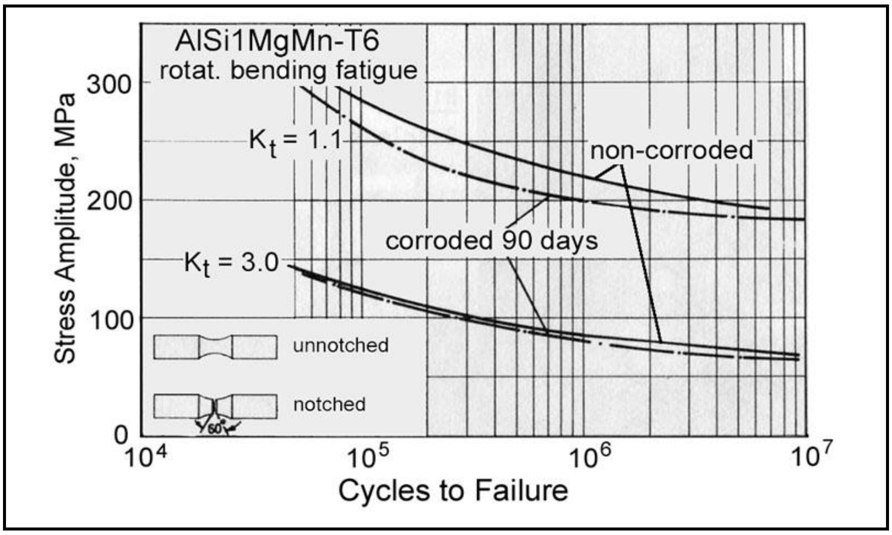
Literature:

- Lowak, H.; Grubisic, V.: Fatigue life prediction and test results of aluminium alloy components. Int. Conference on "Fatigue Prevention and Design", Amsterdam, April 1986
- Ostermann, F.; Hostert, B.: Aluminium für hochbeanspruchte Fahrwerksteile. Fortschr.-Ber.. VDI-Z, Reihe 12, Nr. 34, Oct. 1978
- Ostermann, F.; Hostert, B.: Aluminium für hochbeanspruchte Fahrwerksteile. Fortschr.-Ber.. VDI-Z, Reihe 12, Nr. 34, Oct. 1978

The general corrosion resistance of alloy EN AW-6082-T6 (AlSi1MgMn-T6) is regarded as very good.

When tested acc. to MIL-H-6088 a slight tendency towards intercrystalline corrosion is observed. It is important to note that the resistance against intercrystalline corrosion (IC) depends strongly on the rate of quenching after solution treatment.

The effects of 3 months pre-corrosion by alternate immersion in 3.5% NaCl solution on rotating bending fatigue strength is documented in the figure below. Specimens were stressed in fibre direction. The results show only a moderate loss of fatigue strength.



Corrosion fatigue of 6082-T6, 3 months salt spray prior to test

Source: Ostermann and Hostert, 1978

The typically applied blast cleaning of forgings with aluminium shot is beneficial with respect to corrosion resistance.

4.5 Design guidelines

4.5.1 Fibre orientation and die partition

To achieve a technically and economically sound solution the design of a forged component must be tailored

- to the material and
- to the forging process.

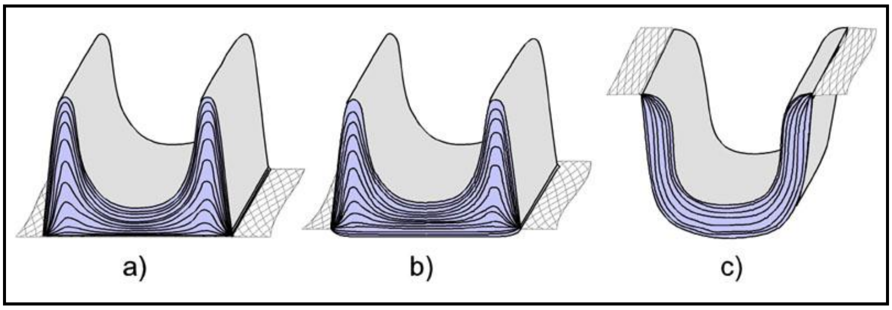
The following describes some rules which should be considered in design of forgings.

Fibre orientation:

Fibre orientation should follow the principle load direction of the part. Fibre orientation is determined by the type of the forging stock, its position in the die and the parting line of the die.
Since these factors largely determine costs and properties of the part, forging experts should be consulted at this stage of design.

Die partitioning:

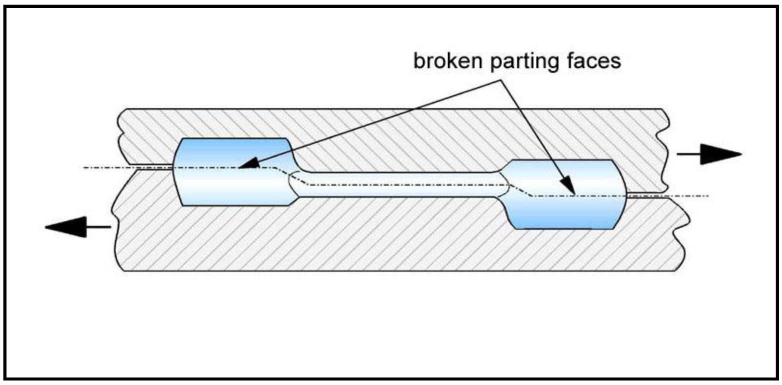
Partitioning of the part's cross section into the die halves affects the fibre flow (see figure below):
a) Good fibre flow and low tooling costs. However, the relatively deep and narrow cavities are difficult to fill.
b) Improved partition, otherwise as a).
c) Undisturbed fibre flow and good filling of cavities. But there will be higher tooling costs because of protrusion of one die face into the other.



4.5.2 Mass distribution and effect of radii on metal flow

Mass distribution and **plane parting faces**:

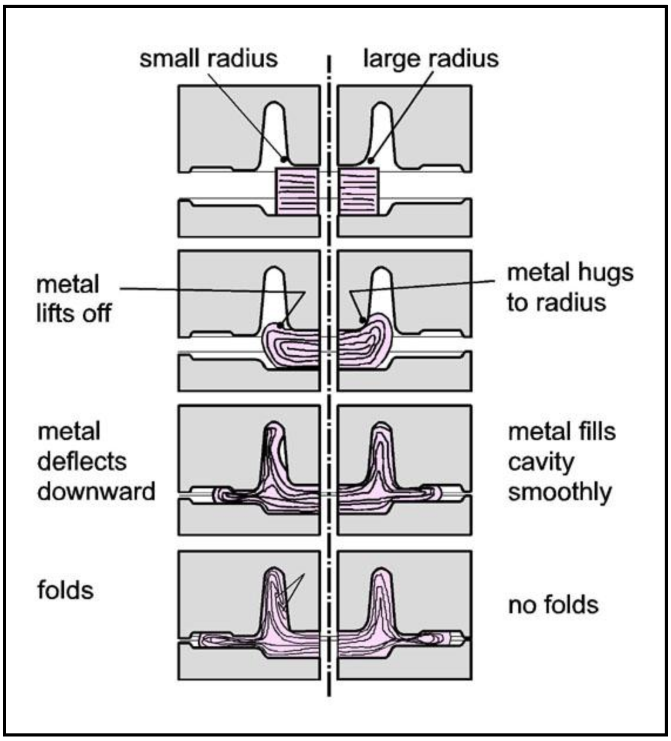
Symmetric mass distribution over the partition of the die is favourable for good material flow (figure below).



However, if this requires broken parting faces, higher die costs, wear and tolerances are to be expected.
Large changes in cross section produce high transverse flow (large flash!) with concomitant danger of fold formation, higher tool wear and detrimental effects on mechanical properties.

Effect of radii on metal flow:

The importance of designing with large radii and soft shape transitions is shown in the figure below. Small radii lead to overshooting of the metal at corners and may produce uncomplete cavity filling and dangerous folds.



Tool manufacture is eased when uniform radii are chosen in designing the part.

Recommended minimum radii are listed in EN 586-3.

4.5.3 Tapers, walls, ribs and bottoms

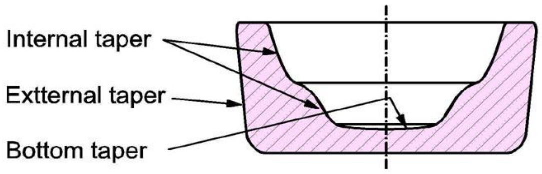
Draft angles (tapers):

A large draft angle facilitates forming and removal of the workpiece from the die. Lower draft angles require tools with strippers.

A bottom taper also facilitates the metal flow.

The draft angle tolerances depend on the dimensions of the part.

Design guidelines according to EN 583-3 are given in the figure below.



	Internal and external taper	Bottom taper
Die with stripper	1°	1°
Die without stripper	3°	1°

Bottoms, walls and ribs:

The standard forging process does not allow producing thin-walled, near-net-shaped forms with narrow tapers because this would require extremely high press forces and raise the risk of structural defects.

Geometrical features with close tolerances required for mechanical fitting and assembly must be machined. Machining is therefore invariably a part of the production process for a finished forged part.

4.5.4 Tolerances

Geometric deviations of the as-forged work piece result from:

- die tolerances,
- wear of die,
- deviations in the process parameters (temperature),
- mismatch of upper and lower die and
- machining allowances.

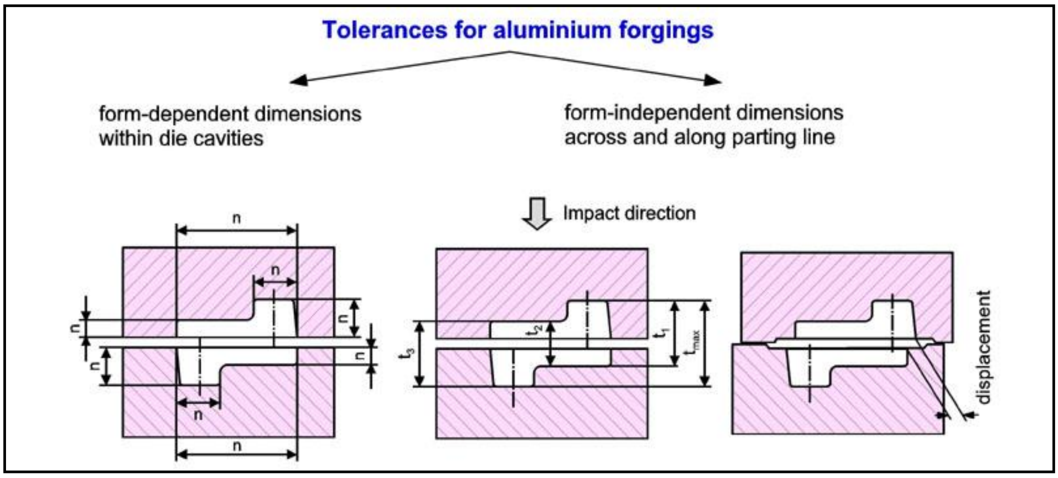
After the forming process, the allowances are machined off. It must be taken into account that machining may cut into the fibre structure and, thus, influence the properties of the component.

The geometric tolerances in aluminium forgings are divided into form-dependent and form-independent dimensions (according to EN 586-3).

Form-dependent tolerances depend only on the geometry of the die cavities and vary with their nominal size.

Form-independent dimensions depend additionally on the closure and flash extension of the die. They depend on the nominal size and content of the projected cross-sectional area.

Tolerances for form-independent dimensions are, as a rule, larger than tolerances for form-dependent dimensions.



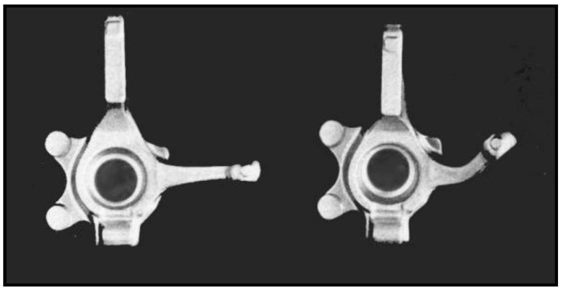
4.6 Crashworthiness

4.6.1 Behaviour of forgings under misuse and crash conditions

Aluminium automotive forgings show a **high structural integrity** and perform well under conditions of misuse or maltreatment, i.e., they deform without disintegration to a point where the proper function is lost so that the part must obviously be replaced. Furthermore, it is a speciality of aluminium and its alloys that its ductility increases with increasing deformation rate, see diagram below.

Aluminium forgings are, therefore, particularly suited for parts which are vital to the safety of the vehicle under critical driving situations.

Front axle housing (6082-T6) with linkage arm deformed by "misuse" (below).

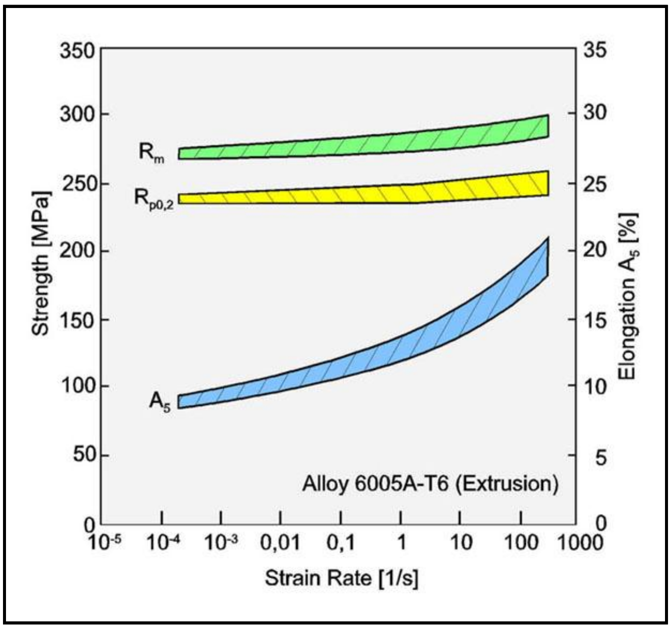


Forged front axle housing, alloy 6082-T6

Misuse test

Source: F. Ostermann and B. Hostert, VAW 1978

Effect of deformation rate on strength and ductility of aluminium alloy 6005A extrusion (below).



Effects of strain rate on mechanical properties of age-hardened 6005A-T6 material

Source: Blauel, IWM

4.7 Fatigue

4.7.1 Fatigue behaviour of forgings

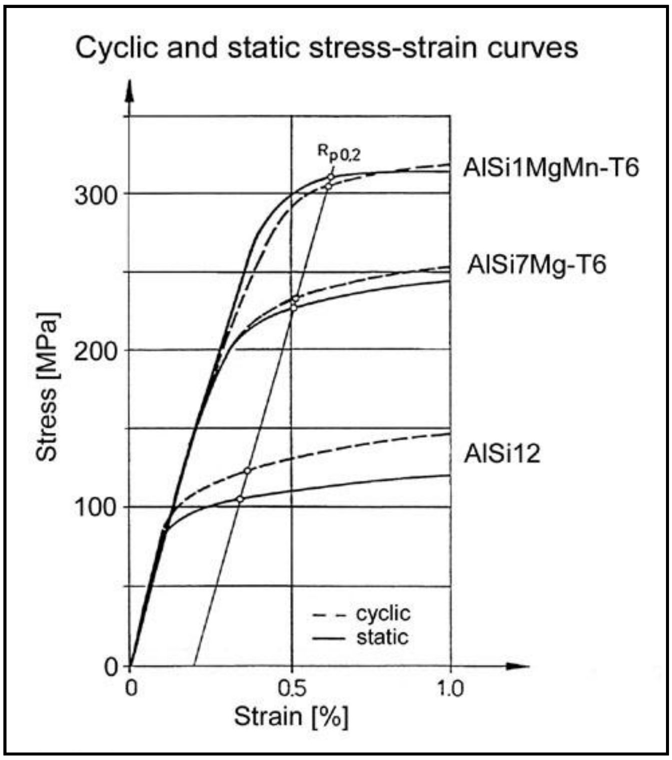
Literature:

- Lowak, H.; Grubisic, V.: Fatigue life prediction and test results of aluminium alloy components. Int. Conference on "Fatigue Prevention and Design", Amsterdam, April 1986

Forgings exhibit **optimum fatigue strength** if the main loading direction coincides with the fibre direction.

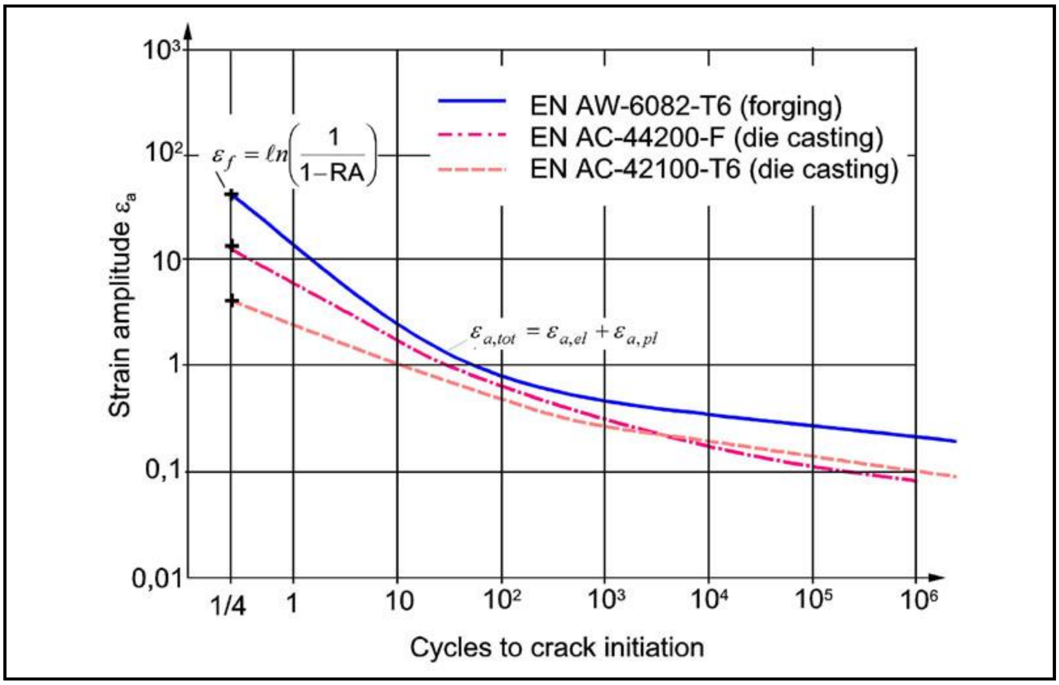
The figures below compare
a) the cyclic and static stress-strain curves of AlSi1MgMn-T6 (EN AW-6082-T6) forgings in comparison with AlSi7Mg-T6 (EN AC-42100-T6) and AlSi12 (EN AC-44200-F) low pressure die castings,
b) the fatigue behaviour of unnotched samples under cyclic strain control.

For a given life time, forged components endure about twice the strain amplitude of cast material.



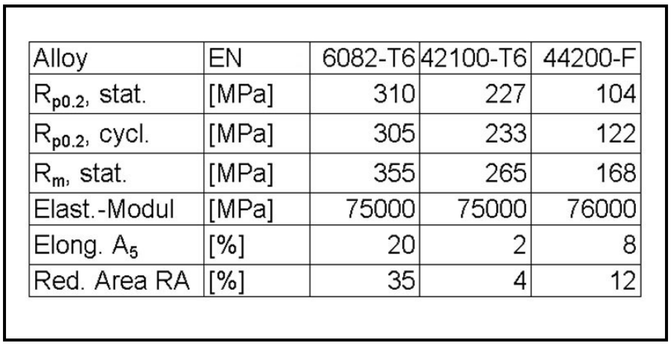
Cyclic and static stress-strain curves of 6082-T6 forging compared with 2 casting alloys

Source: Lowak and Grubisic



Strain controlled fatigue tests of 6082-T6 forging compared with two casting alloys

Source: Lowak and Grubisic



Alloy	EN	6082-T6	42100-T6	44200-F
$R_{p0.2}$, stat.	[MPa]	310	227	104
$R_{p0.2}$, cycl.	[MPa]	305	233	122
R_m, stat.	[MPa]	355	265	168
Elast.-Modul	[MPa]	75000	75000	76000
Elong. A_5	[%]	20	2	8
Red. Area RA	[%]	35	4	12

4.8 Joining of forgings

4.8.1 Connection of forgings to other parts

Literature:

- Lowak, H.; Grubisic, V.: Fatigue life prediction and test results of aluminium alloy components. Int. Conference on "Fatigue Prevention and Design", Amsterdam, April 1986
- Ostermann, F.; Hostert, B.: Aluminium für hochbeanspruchte Fahrwerksteile. Fortschr.-Ber.. VDI-Z, Reihe 12, Nr. 34, Oct. 1978

Automotive forgings are generally joined to other components by mechanical joining, mostly by nuts and bolts made of steel.

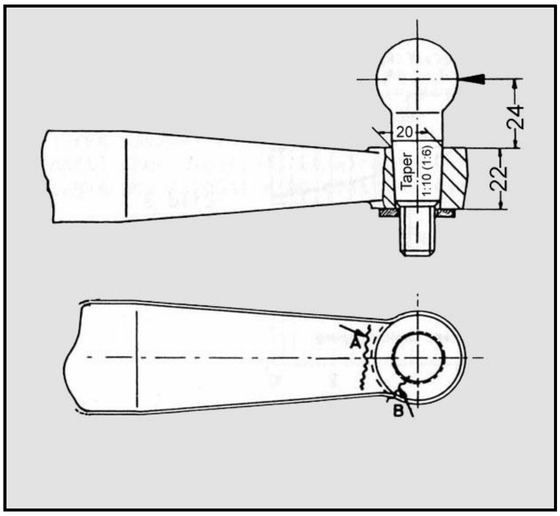
To avoid galvanic corrosion between dissimilar metals, bolts, nuts and washers should have a suitable coating unless the connection is shielded from the environment.

In cases where high (functional) forces are transmitted by the joint, special care must be exercised in the design of such connections like tapered and press fittings. To avoid premature failure under repeated (fatigue) loading, the occurrence of fretting must be avoided.

Connection by ball bearing protected by rubber sleeve (below).

Control arm with ball bearing protected by rubber sleeve

Fretting between tapered seat of ball joint and forging may lead to premature failure at site "B" instead of designed failure point "A" (below).



Source: Ostermann and Hostert