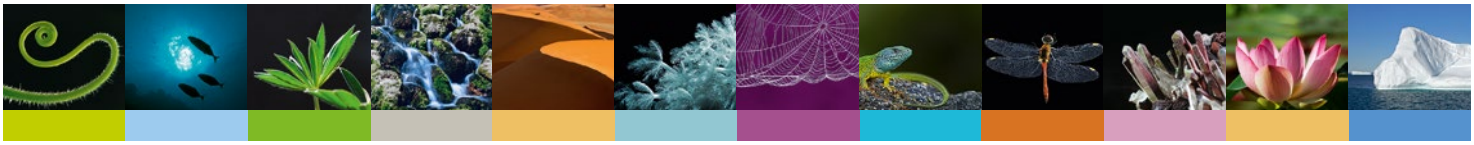


Primary aluminum

# HPDC Alloys for Structural Casts in Vehicle Construction

RHEINFELDEN ALLOYS

RHEINFELDEN

Solutions thru Innovation

# Table of contents RHEINFELDEN ALLOYS – Ductile HPDC Aluminum Alloys for Automotive Structural Applications



# RHEINFELDEN ALLOYS GmbH & Co. KG

RHEINFELDEN
Solutions thru Innovation

**“Progress by tradition”**

ALUMINIUM RHEINFELDEN Group: This history of aluminum in Germany started at Rheinfelden. In 1898 Europe’s first river power station brought about the establishment of the first aluminum smelter in Germany, at Rheinfelden, Baden.
The company has always operated in three business segments and in October 2008 restructuring turned ALUMINIUM RHEINFELDEN GmbH into a holding company and independent GmbH & Co. KGs.
www.alurheinfelden.com

**Our policy**

RHEINFELDEN ALLOYS GmbH & Co. KG: Our innovative character is what allows us to adapt rapidly to fast changing market needs. The agility of a private family owned operated company, the central geographic location in the European casting metal market, the know-how and experience of our team, are factors making a difference for customers looking for reliable tradition and modern innovation. Efficient and effective use of casting aluminum is on the forefront of our new developments in materials.

It is RHEINFELDEN ALLOYS philosophy to fulfill requested standards of quality, either ISO/IATF or VDA. Please ask for our actual certificates or have a look at our homepage.

Products of RHEINFELDEN ALLOYS can be found wherever steel designs or iron casts can be replaced by light aluminum casts. RHEINFELDEN ALLOYS is a powerful partner, especially to the automotive and mechanical engineering sectors in providing alloys designed to the process and cast part based on the customer’s particular needs. We also offer papers like this handbook about favorable alloys for designers of structural die-casts.
www.rheinfelden-alloys.eu · Tel. +49 7623 93 490

We offer customized alloys and new solutions for high performance materials and light weight components with focus on low carbon foot print products. In this mood we developed new high strength die-casting alloys and an innovative alloy family for structural casts in the automotive industry.

Please have a look to our alloy selecting tool:
www.rheinfelden-alloys.eu/alloytoy

RHEINFELDEN-Ingot

Panoramic view of the entire RHEINFELDEN ALLOYS complex

# R & D and Customer Support

When RHEINFELDEN ALLOYS develop new materials we always aim to achieve efficient and specific use of aluminum casts. Through the use of materials, tailored and refined to increase performance, RHEINFELDEN ALLOYS is constantly striving to help reduce vehicle weight and therefore cut emissions. We run development projects with the goal to optimise the mechanical and casting properties of our aluminum HPDC alloys. Our recent developed alloys are Silafont-38, Magsimal-plus and Castaduct-42.

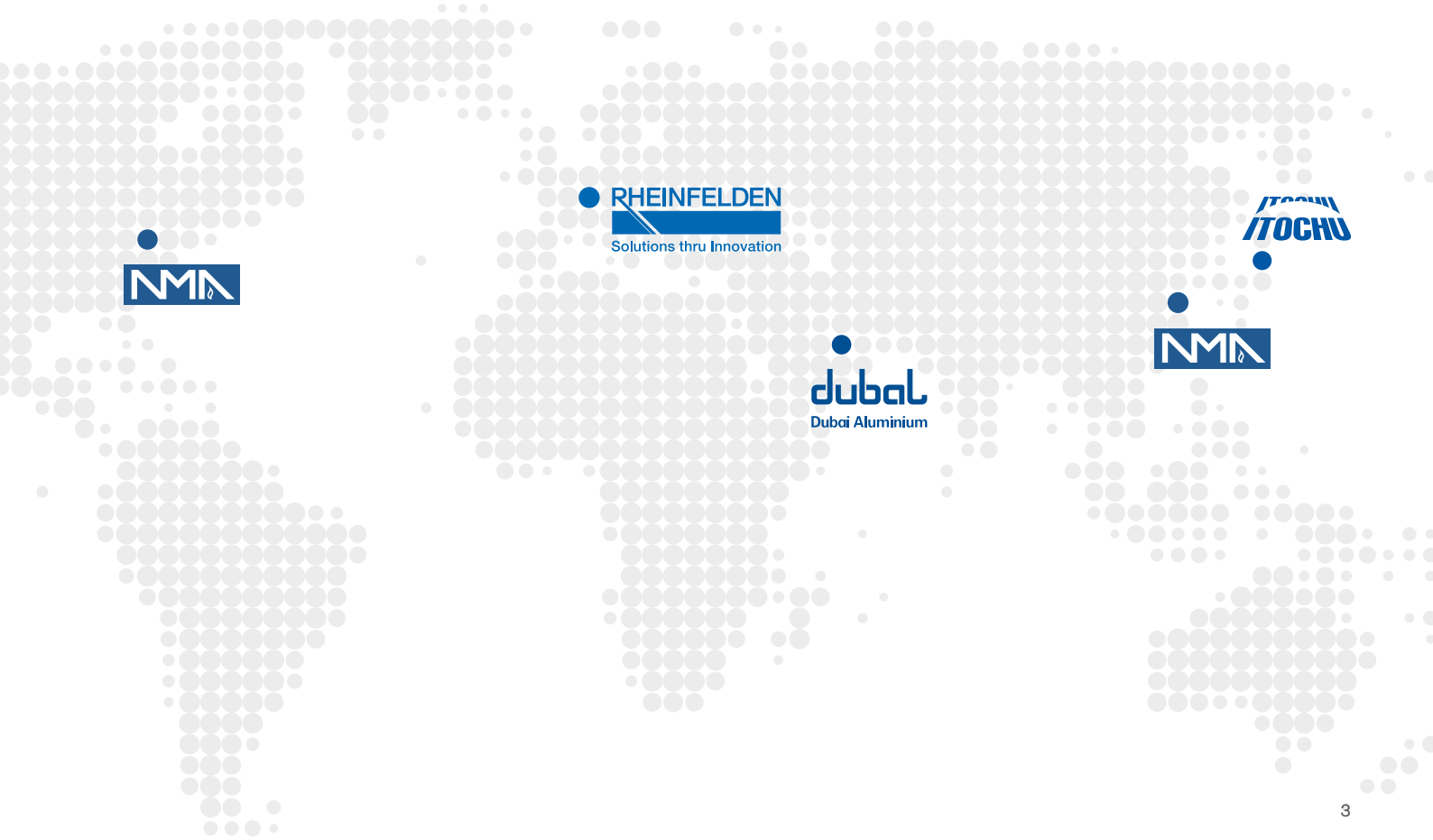
**RHEINFELDEN Customer Support and RHEINFELDEN TechCenter**

Every product and every customer has individual requirements of the material. The Customer Support Team at RHEINFELDEN ALLOYS has the job of anticipating these needs and producing tailored materials, fitting the casts and your requirements. Please contact our Customer Support Team and use our TechCenter installations at RHEINFELDEN ALLOYS also for your foundry concerns. We can advise on the use and design of casts and the choice of alloy. Use our experience for your success as RHEINFELDEN ALLOYS customer.

**RHEINFELDEN alloys globally**

Our development of special HPDC alloys results to patents for Castasil-21, Castasil-37, Magsimal-59, Magsimal-plus and pending patents in 2017 for Castaduct-42 and Silafont-38. Our license partners produce these alloys globally, especially DUBAL in Dubai, NIKKEI NMA in North America and also in China.

In this cooperation all here described alloys are available globally. Please ask for a possibility of local production by our partners.



# Alloys for Structural Casts by RHEINFELDEN ALLOYS

**Structural components**

Casted structural components are mostly large, but always stability defining parts. They fulfill the idea of lightweight by dimensional stability and functional integration. In the case of a crash high energy absorption is recommended.

Dimensional stability is during the production process positively influenced by

- Easy castability
- Suitable die-cast design
- High strength achieved without heat treatment

RHEINFELDEN ALLOYS, as alloy producer support the use of casted structural components and developed several HPDC alloys for that purpose. Silafont-36, Castaman-35 as AlSi10MnMg alloys are established since years. This handbook summarizes the new alloys for structural casts.

**HPDC ALLOYS FOR STRUCTURAL APPLICATIONS**

- **Silafont-36, AlSi10MnMg**
- **Silafont-38**
- **Castasil-37**
- **Magsimal-59**
- **Magsimal-plus**
- **Castaduct-42**

**Quick finder for selecting the right alloy**

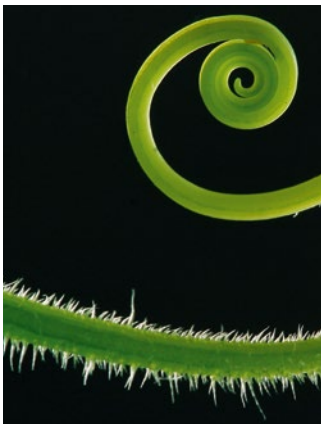
The following table provides an overview of RHEINFELDEN ALLOYS' new alloys. The existing alloys are described in former handbooks in detail. The new alloys were developed for structural, cases and chassis components as well as for battery, electric motor and high-voltage applications in the field of E-mobility.

| Alloy | Chemical denomination | Structural application | Electrical application | HPDC castability | Strength in as-cast state | Electrical conductivity | Suitable for technical anodising | Suitable for punch riveting | Elongation | Hardness | Corrosion resistance | Thin wall application | Impact toughness/ductility | Weldability | Flangeability | Machinability at F | Machinability following T6 | High temperature application | Stable mechanical properties after long-time heating |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Silafont-38** | **AlSi9MnMgZn** | ● | – | ● | ◕ | – | ◐ | ◕ | ◕ | ◕ | ◕ | ◕ | ◕ | ● | ◐ | ◕ | ◕ | ◔ | ◔ |
| **Castasil-37** | **AlSi9MnMoZr** | ● | – | ● | ◕ | – | ◕ | ◕ | ● | ◐ | ◕ | ● | ◕ | ● | ◐ | ◕ | – | ◔ | ● |
| **Castasil-21** | **AlSi9SrE** | – | ● | ◕ | ◐ | ◕ | ◕ | ◕ | ◕ | ◐ | ◕ | ◕ | ◐ | ● | ◕ | ◕ | – | ◔ | ● |
| **Magsimal-59** | **AlMg5Si2Mn** | ● | – | ◐ | ● | – | ◕ | ● | ● | ◐ | ● | ● | ● | ● | ◕ | ● | – | ◐ | ◐ |
| **Magsimal-plus** | **AlMg6Si2MnZr** | ● | | ◐ | ● | – | ◕ | ◕ | ● | ◐ | ● | ● | ● | ● | ◐ | ● | – | ◕ | ◐ |
| **Castaduct-42** | **AlMg4Fe2** | ● | – | ◕ | ◕ | – | ● | ● | ● | ◐ | ● | ● | ● | ● | ● | ● | – | ◐ | ● |

● excellent ◐ good ○ poor
◕ very good ◔ all right – not applicable

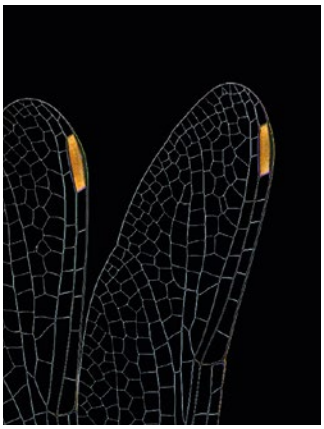
## Silafont® – an infinite wealth of properties

A family of materials which can be adapted to the part specifications and to the customer's individual production process with ultimate precision. Can be easily processed, outstanding flow properties, is modified with strontium to further enhance properties. Silafont is for complex, delicate components which have to satisfy precisely defined requirements and, if they feature the right components, make maximum production efficiency possible. Silafont emulates flowing water that flows around every stone and fills every cavity. > page 6 – 11



## Castasil® – large surface, high dimensional stability, fantastic to cast

An alloy, produced for large HPDC structural parts in the automotive industry. In the meantime several OEMs recognized the advantages of these alloys for car structural or electrical applications: high dimensional stability, can be used without heat treatment, shape well and easy to weld, or by Castasil-21 with highest electrical or thermal conductivity.
Nature's equivalent: the vine shoot which turns towards the sun, flexible, elastic and yet incredibly tough and strong. > page 12 – 17



## Magsimal® – of filigree lightness, but extremely resilient

An alloy family for delicate parts which need to retain their strength and precise form over a long period. Good weldability, high resilience, can be used in virtually any application. Supreme corrosion resistance, even to salt water.
Parts which simulate the structure of the wings of a dragonfly: wafer thin, elastic and yet offering incredible strength and resilience, they enable this dainty insect to fly distances that never cease to amaze. > page 18 – 25

## Castaduct® – Always fascinating pliable down to the finest detail

An innovative HPDC alloy family also for large-area components like structural casts in thin-walled design. Modern lightweight construction is easy to realize thanks to excellent castability, use in the as-cast state and a smart alloy composition with its low specific weight, even for higher temperature applications in battery housings of the E-cars.
The temperature-loving Emerald lizard produces the same fascination with her long flexible body > page 26 – 35

# Silafont®-38 (Sf-38)

An infinite wealth of properties

Example of use

The HPDC alloy Silafont-38 was developed by RHEINFELDEN ALLOYS to further increase yield strength compared to Silafont-36 without significant change in ductility.

Several hardening elements are alloyed in defined ranges in the Silafont-38. That's the cause why the advantage is with a T6 heat treatment. The first step – solutionizing – is still necessary, but the cooling may differ.

Even with an air quenching to lower distortion the complex alloyed Silafont-38 reaches 180 MPa yield strength after artificial aging.

Besides these moderate cooling rates it is possible to cool down with water after the solutionizing treatment to achive highest strength.

Additionally Silafont-38 has also following properties required for the pressure die-casting process:

- excellent castability even with varying wall thicknesses
- no sticking to the mold; the low-iron Silafont-38 is therefore alloyed with manganese and strontium
- excellent machinability

In more and more applications, mainly in car manufacturing, other properties of Silafont-38 are of increasing importance:

- good corrosion resistance due to specially balanced composition
- high fatigue strength and crash performance due to reduced effect of disturbing Fe and Si phases
- excellent weldability for aluminum profile – cast designs
- suitable for self-piercing riveting

**KEY FIGURES of Silafont-38**

- no sticking to the mold; the low-iron Silafont-38 is therefore multi element alloyed
- very high YTS in conjunction with T6 including air quenching
- good corrosion resistance due to specially balanced composition
- excellent weldability for wrought aluminum profile – cast designs
- suitable for self-piercing riveting

# Silafont®-38 [AlSi9MnMgZn]

RHEINFELDEN
Solutions thru Innovation

**Areas of use**

Light-weight car body structures for vehicles, gearboxes, battery housings mechanical engineering.

**Chemical composition of Silafont-38 in the ingot** [% of mass]

| [%] | Si | Fe | Cu | Mn | Mg | Zn | Ti | Zr | others |
|---|---|---|---|---|---|---|---|---|---|
| min. | **8.5** | | **0.1** | **0.4** | **0.3** | **0.1** | | **0.1** | |
| max. | **10.0** | 0.15 | **0.4** | **0.8** | **0.4** | **0.3** | 0.15 | **0.3** | **Mo; Sr** |

**Mechanical properties**

| Casting method | Treatment state | Quenching cooling | YTS $R_{p0.2}$ [MPa] | UTS $R_m$ [MPa] | Elongation E [%] |
|---|---|---|---|---|---|
| **HPDC** | **F** | | **135–160** | **270–300** | **4–8** |
| **HPDC** | **T6** | **Water** | **230–280** | **300–350** | **6–9** |
| **HPDC** | **T6** | **Air** | **180–210** | **250–290** | **8–11** |

**Physical data**

| Density [kg/dm³] | Coefficient of thermal expansion [1/K × $10^{-6}$] | Thermal Conductivity [W/(K × cm)] | ElectricalConductivity [% IACS] | Shrinkage [%] |
|---|---|---|---|---|
| **2.69** | **21** | **1.5** | **36.0–41.5** | **0.4–0.6** |

**KEY FIGURES of Silafont-38**

- **Further development of the well-known Silafont-36** for the use in ultra-high strength and crash-relevant structural parts in the automotive industry.
- **Complex alloyed Primary Aluminum HPDC alloy with low Fe content.** Also a Strontium permanent modification for very high elongation with good ductility.
- **Low distortion T6 heat treatments with cooling in moving air** could be realized (Cooling rate after solution treatment: at least 3 °C/s down to 200 °C).
- **Excellent dynamic fatigue strength.**
- **Very suitable for applications in vehicle designs.** Heat treatable to high elongation and high energy absorption capability.

- **Replaces steel sheet constructions in vehicle designs.**
- **Allows weight reductions of up to 40 %** compared to die-casting standard alloys in the field of vehicle structural parts.
- **Excellent machinable and very good suitable for all welding processes.**
- **Very suitable for riveting** with applicable riveting processes and tools.
- **Very good corrosion resistance:** Coatings may be unnecessary.
- **Excellent castable HPDC alloy:** Solidification range, shrinkage behavior and expected mold endurance are comparable to that of AlSi9 and AlSi10Mg alloys.
- Best mold release: No sticking to the mold.
- Excellent castable for casts with wall thickness above 1.5 mm.

# Silafont®-38 [AlSi9MnMgZn] – Properties

| [%] | Si | Fe | Cu | Mn | Mg | Zn | Ti | Zr | others |
|---|---|---|---|---|---|---|---|---|---|
| min. | **8.5** | | **0.1** | **0.4** | **0.3** | **0.1** | | **0.1** | |
| max. | **10.0** | 0.15 | **0.4** | **0.8** | **0.4** | **0.3** | 0.15 | **0.3** | **Mo; Sr** |

Tab.1: Chemical composition of Silafont-38, AlSi9MnMgZn in the ingot (in mass-%)

Requirements for lightweight construction with the aim of higher strength for thin-walled designs in structural casts are constantly increasing. The potential of Silafont-36, the structural alloy known worldwide as the standard, continues to be exploited, especially by optimizing the die-casting and heat treatment processes. RHEINFELDEN ALLOYS has achieved a further increase through an alloy engineering development in conjunction with a low-distortion heat treatment method with the Silafont-38 described here.

**Alloy description**

In the development of the alloy Silafont-38, particular attention was paid to the castability (Tab. 1). Generally, castability is comparable to a Silafont-36. The wider solidification interval due to the higher concentration of copper and zinc even increases the mold filling capacity. A further reduction of the silicon would increase the elongation, but then reduces the very good flowability.

The sticking tendency is reduced primarily by the high manganese content, but also by iron and strontium. In this AlSi alloy, the Mn content crystallizes in hexagonal $Al_6Mn$ intermetallic phases; a crystal form that allows high deformations of the cast, since there are no serious sharp edges in the microstructure of the casting alloy. Several casting tests confirmed the good castability of the Silafont-38.

The increase in strength through a T6 heat treatment is achieved primarily by intermetallic phases with magnesium, copper and to a lesser extent also by zinc. Magnesium in an alloy range of 0.28 to 0.35 % allows a good increase in T6 strength, even if this process is performed as a low-distortion variant in the air stream. Molybdenum is dissolved in the α-crystal of aluminum and forms no detectable by light microscopy phases. Nevertheless, this alloying increases strength starting from a content of 0.10 %.
In contrast, zircon has a content of 0.10 % as a strength-enhancing grain refiner.

The set in close tolerances levels of magnesium and copper give in this ratio a good corrosion resistance, since so the formation of corrosion-promoting intermetallic phases is not promoted. Although higher levels of Cu would lead to an increase in the yield strength, but worsen the corrosion behavior.

**Modification**

The modification of the AlSi eutectic is achieved by the addition of strontium (Sr) and favors a very fine, coral-shaped solidification of the silicon in the eutectic. This refinement is achieved in die-casts of Silafont-38 with a Sr content above 80 ppm.
Above a level of 350 ppm Sr, the general tendency of the melt to oxidize increases, which would lead to an increased hydrogen content of the melt. This should be considered in structural casts for welded assemblies, as this is also a cause of weld porosity. Metallurgically, only a Sr content above 450 ppm leads to the formation of coarser, moreover Mg-containing mixed crystals, that is to say for over-refinement. A reduction in elongation can then be seen as well.

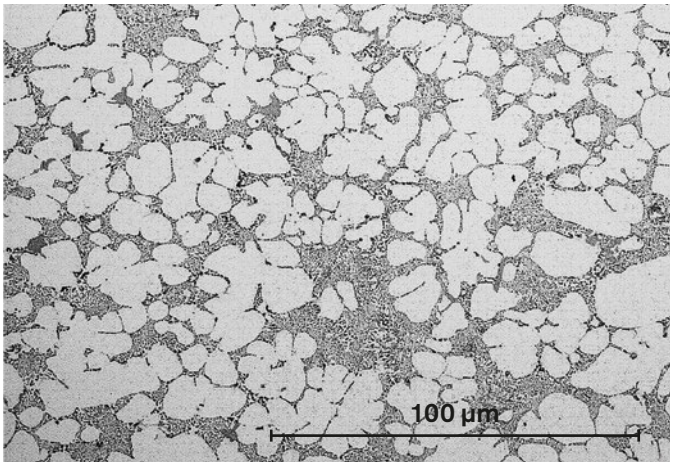



Fig.1a: Microstructure of Silafont-38, AlSi9MnMgZn, in the as-cast state, 3 mm sample plate

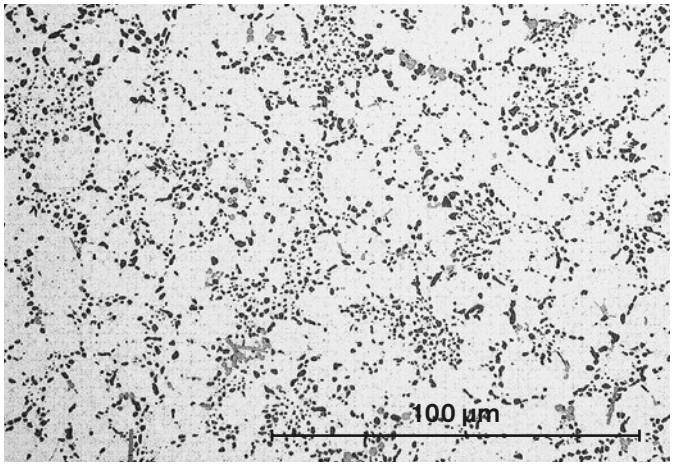



Fig.1b: Microstructure of Silafont-38, AlSi9MnMgZn, in the T6 state

**Metallography and phase simulation**

In Fig. 1a, metallographic microstructures from the die-casted alloy are shown in 500-times magnification. In condition F, a very fine eutectic can be seen, which allows a very high deformability already in the as-cast state. Intermetallic phases are under 10 microns in size, thus very small and evenly distributed.

The solidification of Silafont-38 starts with the $Al_6Mn$-containing phase at about 600 °C. Essential for the alloy, however, is the formation of the modified Al-Si eutectic at 550 °C. A fine distribution of the AlMnFeSi phase is necessary for a high ductility and is typically maintained in the die-cast structure with an Mn content of between 0.4 and 0.8 %. The intermetallic Zr phases also influence a fine structure of the Silafont-38.

For strength, submicroscopic precipitates in the Al solid solution are essential. Such precipitates can be calculated using a phase simulation. Fig. 2 shows the metastable MgSi phases, which decisively influence the strength. For their shape, the initial state of the material produced by the casting process, the solution annealing and the quenching condition is important. If they have a suitable size, they lead to high strength of the casting material.

**Heat treatment**

In the TechCenter Rheinfelden die-casted plates of dimension 200 × 60 mm are poured and T6 heat treated (Fig. 1b). An adjustment of the material characteristics achievable on 3 mm test plates with large-area structural casts took place. The mold filling of these panels resembles that of high-quality cast large structural casts more than might be expected. A significant difference is the quench rate after removal from the mold or after the heat treatment. Small plates can quench significantly faster, which has an effect on material properties. The achievable strengths, especially at the yield strength, increase considerably. For this reason, a heat treatment installation has been built up which approximates the quenching conditions of an industrial production. The quench rate was set at 3 °C/s for this laboratory method.

Fig. 3 shows temperature curves of 3 mm plates at different quenching conditions. Clearly, the rapid temperature cooling when immersed in water can be seen. After removal from the oven, the onset of cooling only delayed by 8 seconds. The different measuring curves when cooling with air are also due to the different intensity of the air flow. In terms of metallurgy, it is important to cool down to around 200 °C, below which the cooling may then proceed more slowly.

With this determination, material characteristics such as Tab. 2 and Fig. 4 could be measured on test plates in the TechCenter. These are comparable to those from typical industrial production processes.

Silafont-38 can also be cooled down after solution annealing with a considerably faster air cooling, as well as with the special water-polymer cooling Aluquench®. The material characteristic values are shown as the mean value of about 50 samples each in Tab. 3. The respective increase of the yield strength from the solution annealed state follows the higher cooling rates of these processes.

Typically, with faster cooling, the distortion increases due to higher residual stresses. Only the water-polymer cooling of the Silafont-38 achieves maximum strength without significant distortion. With water cooling, there is always a higher distortion of the structural cast geometry.

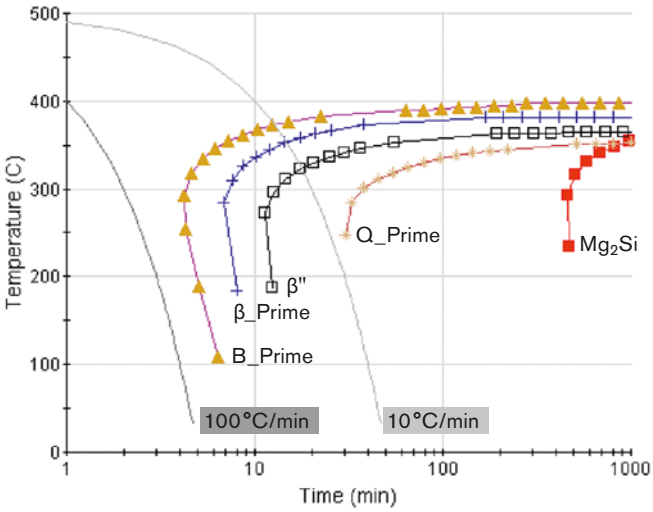



Fig. 2: Calculated phase diagram for the time temperature curves of the different MgSi precipitations in Silafont-38

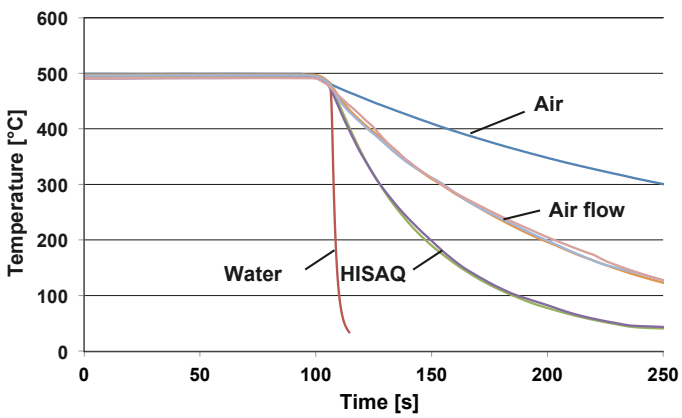



Fig. 3: Cooling curves with different cooling agents at 3 mm HPDC plates

# Silafont®-38 [AlSi9MnMgZn] – Properties

| Casting Method | Treatment state | Quenching cooling | YTS $R_{p0.2}$ [MPa] | UTS $R_m$ [MPa] | Elongation E [%] |
|---|---|---|---|---|---|
| HPDC | F | | 138 | 299 | 8.4 |
| Standard deviation | | | 3 | 8 | 0.8 |
| HPDC | T5 | Water | 220 | 317 | 6.2 |
| Standard deviation | | | 4 | 7 | 0.3 |
| HPDC | T6 | Air 3 °C/s | 192 | 264 | 10.5 |
| Standard deviation | | | 9 | 7 | 1.4 |

Tab. 2: Mechanical properties of Silafont-38, AlSi9MnMgZr plates in comparison F to T5 water cooled and T6 air cooled; the standard deviation is calculated of 50 casts

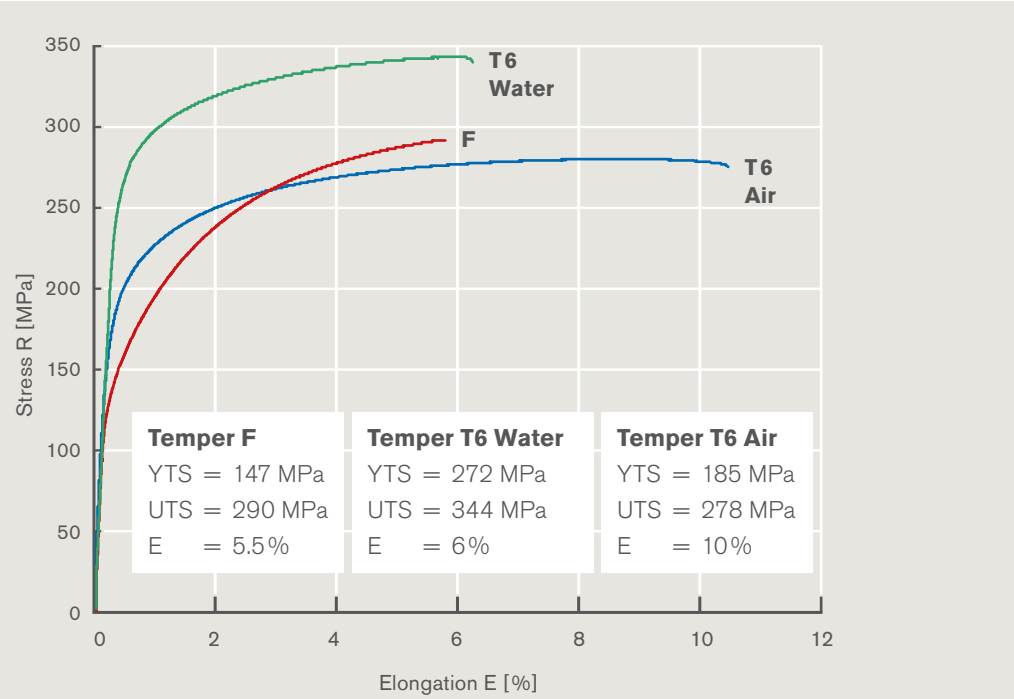



Fig. 4: Stress-strain curve for Silafont-38, AlSi9MnMgZr, as-cast state and T6 cooled with air or water

| Casting Method | Treatment state | Quenching cooling | YTS $R_{p0.2}$ [MPa] | UTS $R_m$ [MPa] | Elongation E [%] |
|---|---|---|---|---|---|
| HPDC | F | | 138 | 299 | 8.4 |
| HPDC | T6 | Air 3 °C/s | 192 | 264 | 10.5 |
| HPDC | T6 | Air > 10 °C/s | 209 | 288 | 11.0 |
| HPDC | T6 | Aluquench | 257 | 332 | 10.0 |
| HPDC | T6 | Water | 272 | 344 | 6.0 |

Tab. 3: Mechanical properties of Silafont38, AlSi9MnMgZn in the T6 state and with different cooling agents

This shows the importance of the high alloy content in the Silafont-38 in order to achieve the requirements of mechanical properties with minimal component distortion.

**Short-term and long-term stability**

Aging of the casts is tested by testing at 205 °C for 1 hour and at 150 °C for 1000 hours. Thereafter, the mechanical properties of the components made of Silafont-38 must not have fallen below the specifications of mechanical strength.
Silafont-38 has passed this after heat treatment with the air quenching used here at 3 °C/s after solution annealing.

**Rivetability**

The strength of a material affects the rivetability. Materials with higher strengths must be joined with other rivets than materials with low strengths. For this reason, the rivet geometry and parameters of the die-casting alloy Silafont-38 have been adjusted. The high deformability of the Silafont-38 led to crack-free riveted joints.

**Weldability**

In addition to high material parameters, good weldability is required for structural casts.

To check the weldability, a production-accompanying, manually executed welding test can be carried out. Such a test result with Silafont-38 is shown in Fig. 5 compared to the standard Silafont-36 alloy. Both results are far beyond the requirements.

**Corrosion resistance**

A salt spray test (ISO 9227) and an intercrystalline corrosion test (ASTM G110-92) were performed at external laboratories. The corrosion behavior of 3 mm sheets of Silafont-38 in this case was compared with that of Castasil-37, AlSi9MnMoZr.
The corrosion-influencing difference to this alloy is in the higher levels of Cu and Zn, as well as Mg in the Silafont-38.
The evaluation after 336 hours of spray test revealed a similar corrosion resistance of the two alloys. One difference was in the nature of the corrosion attack. Castasil-37 as a high-purity alloy tended to pitting corrosion, while the zinc and copper fractions of Silafont-38 were more likely to cause areal corrosion.

**Case study**

A HPDC test was also carried out on the structural casts as in Fig. 6, which is installed as a door frame reinforcement of a convertible. It is characterized by high strength requirements for the crash-relevant components with a wall thickness of up to 2.1 mm. The aim was to top yield strength of 180 N/mm² with at least 8 % elongation.

This sophisticated component has been previously die-casted in series in the alloy Silafont-36 with Mg 0.35 % with a T6 heat treatment with water quenching after solution annealing.
With unchanged pouring parameters, Silafont-38 was changed to a T6 heat treatment with air-shower quenching after solution heat treatment.

With the help of a vacuum-assisted casting technology, the structural casts (Fig. 6) was casted in a “double cavity” mold. The characteristic values from Tab. 2 were achieved in the as-cast condition. Further, the T5 condition was achieved by quenching in water after casting. Cooling after solution heat treatment at T6 was performed by an air shower at 3 °C/sec. These are averages of about 50 tensile bar samples; the standard deviations is also given.

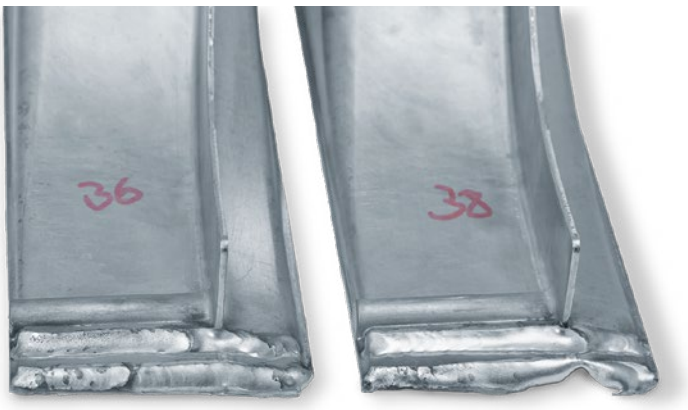



Fig. 5: Welding beam on tested structural part, Silafont-36 (left) and Silafont-38 (right)

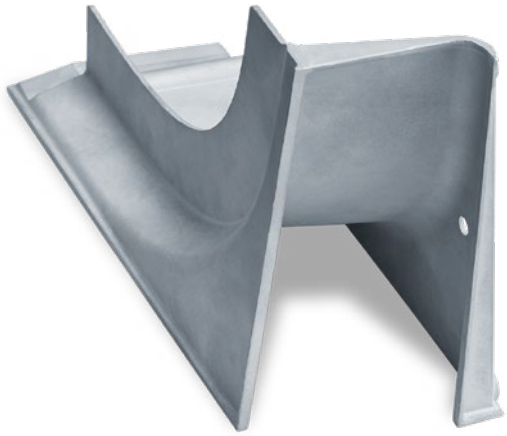
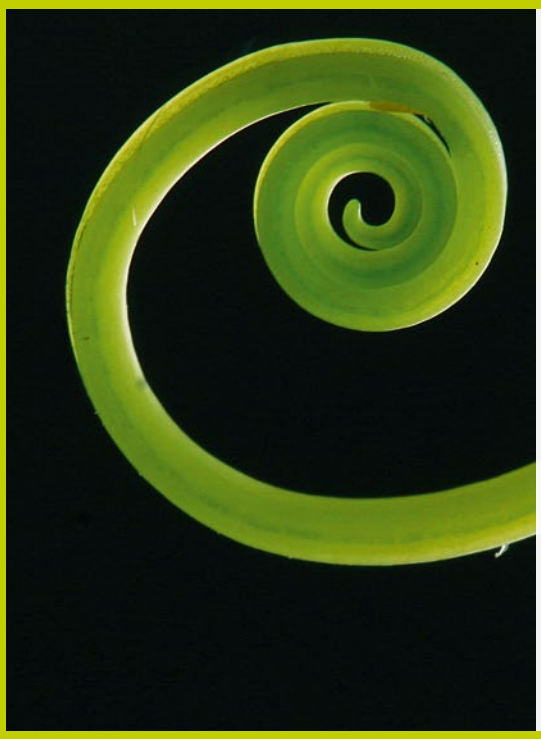
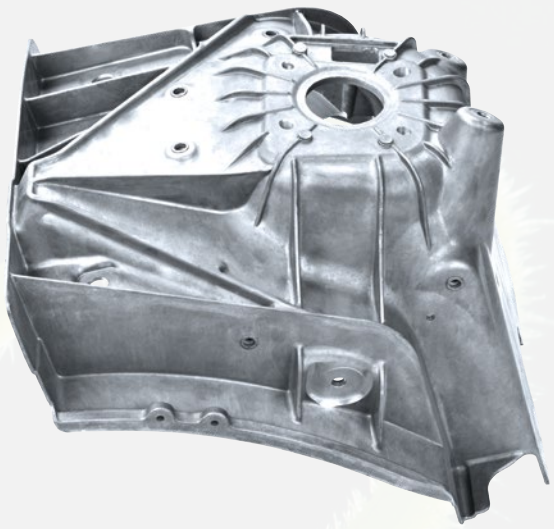


Fig. 6: Door frame reinforcement, Silafont-38 T6 Air quenched

# Castasil®-37 (Ci-37)

Large areas, high dimensional stability, fantastic to cast





Example of use

Development by RHEINFELDEN ALLOYS Castasil-37 shows good mechanical properties, especially elongation, which are superior to those of conventional AlSi-type alloys. Out-standing castability and weldability enable the casting of complex designs. Self-piercing riveting trials in the as-cast state led for example to good results.

The properties are mainly influenced by alloying with silicon, manganese, molybdenum and strontium. A low magnesium content is essential for the excellent stability of long-term stability of mechanical properties.

Specially chosen chemical composition enables the following casting properties:

- excellent castability
- suitable for minimum wall thicknesses
- no sticking to the mold

With increasing number of applications, mainly in car manufacturing, other properties of Castasil-37 became also important:

- high fatigue strength
- very good corrosion resistance
- excellent weldability
- excellent machinability
- suitable for self-piercing riveting
- suitable for adhesive bonding applications

**KEY FIGURES of Ci-37**

- suitable for different wall thicknesses
- highest fatigue strength compared to AlSi-alloys
- very good corrosion resistance
- no aging, best dimensional stability in as-cast
- suitable for adhesive bonding applications

# Castasil®-37 [AlSi9MnMoZr]

RHEINFELDEN
Solutions thru Innovation

### Areas of use

Connection nodes for space frame designs; thin-walled body parts; architecture, cars, lighting, aircraft, domestic appliances, air conditioning, automotive engineering, foodstuffs industry, mechanical engineering, shipbuilding, defence engineering; replaces high pressure die-casts with T7 or T6 with air quenching.

### Distinguishing characteristics

HPDC alloy with excellent castability. Very high elongation in as-cast state as a result of which it can be used in more ways when in as-cast state. Further increase in ductility thanks to single-stage heat treatment. No distortion or blisters from solution heat treatment, very good corrosion resistance, no long-term ageing due to heat, good machinability, ideal for riveting and adhesive bonding in automotive engineering.

### Chemical composition of Castasil-37 in the ingot [% of mass]

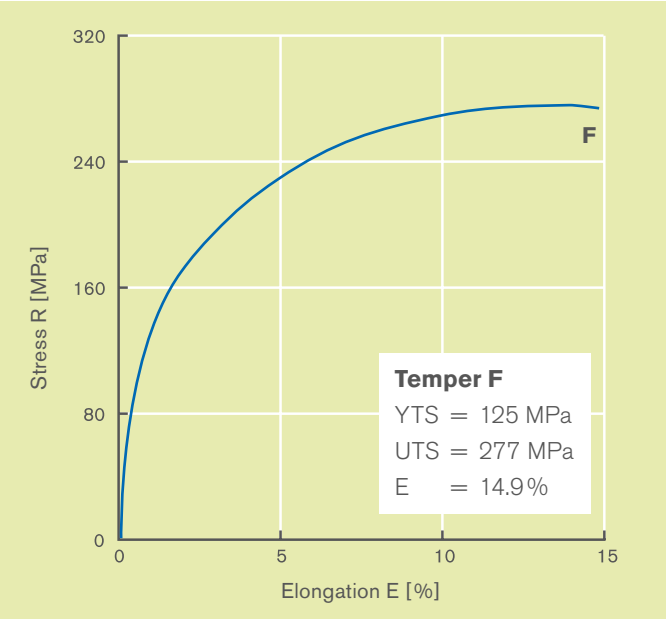
| [%] | Si | Fe | Cu | Mn | Mg | Zn | Mo | Zr | Ti | Sr | others |
|---|---|---|---|---|---|---|---|---|---|---|---|
| min. | **8.5** | | | **0.35** | | | **0.1** | **0.1** | | **0.006** | |
| max. | **10.5** | 0.15 | 0.05 | **0.6** | **0.06** | 0.07 | **0.3** | **0.3** | 0.15 | **0.025** | 0.10 |

### Mechanical properties

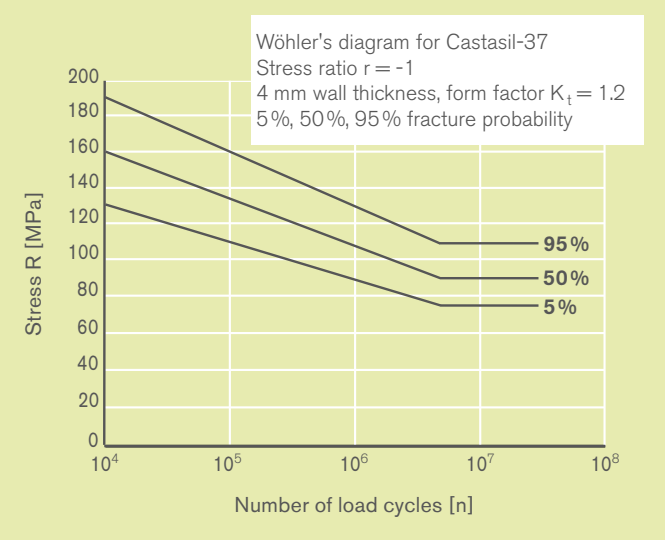
| Wall thickness [mm] | YTS $R_{p0.2}$ [MPa] | UTS $R_m$ [MPa] | Elongation E [%] |
|---|---|---|---|
| **2 – 3** | **120 – 150** | **260 – 300** | **10 – 14** |
| **3 – 5** | **100 – 130** | **230 – 280** | **10 – 14** |
| **5 – 7** | **80 – 110** | **200 – 250** | **10 – 14** |

### Physical data

| Density [kg/dm³] | Coefficient of thermal expansion [1/K × $10^{-6}$] | Thermal Conductivity [W/(K × cm)] | ElectricalConductivity [% IACS] | Shrinkage [%] |
|---|---|---|---|---|
| **2.69** | **22** | **1.4** | **31.0 – 38.0** | **0.4 – 0.6** |



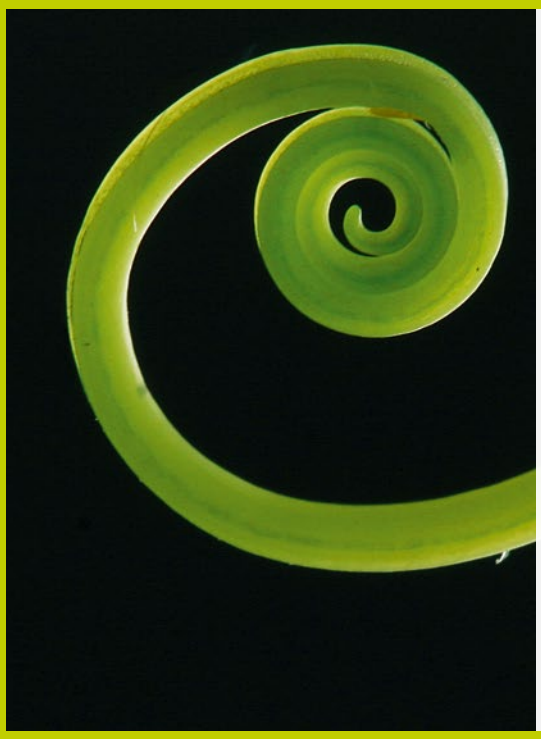

Stress-strain curve for Castasil-37, AlSi9MnMoZr, in the as-cast state (F)

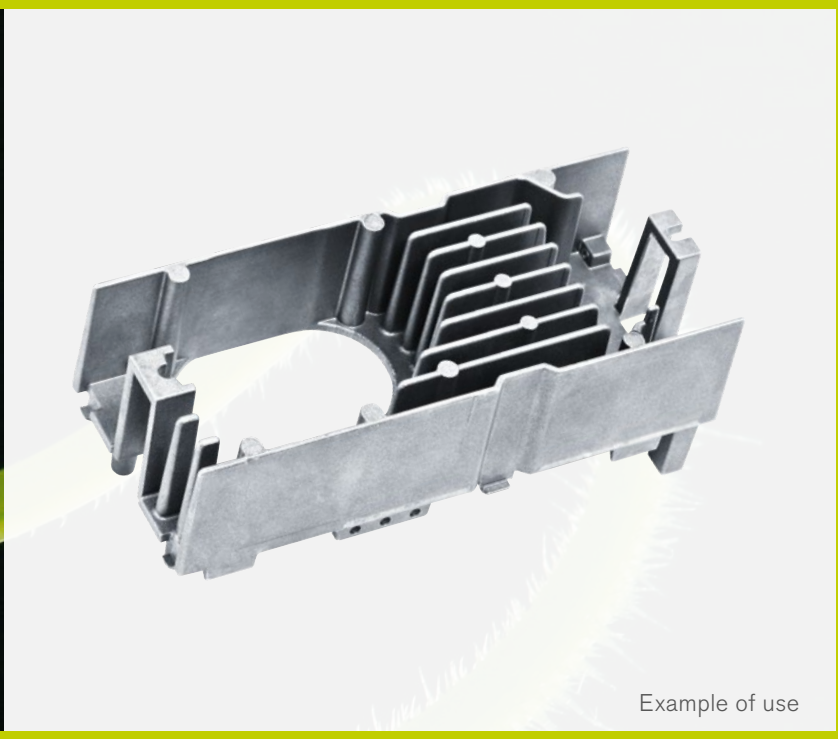



Wöhler's diagram for Castasil-37, AlSi9MnMoZr, in the as-cast state (F)

# Castasil®-21 (Ci-21)

Large areas, high dimensional stability, fantastic to cast





Example of use

Castasil-21 is a HPDC alloy developed by RHEINFELDEN ALLOYS for casts with outstanding requirements in terms of electrical or thermal conductivity.
Aluminum 99.7E for rotors has indeed higher electrical conductivity, but in praxis you need lower contraction for huge casts, like with an alloy with more than 8 % silicon.

The application of Castasil-21 may help to lower the weight of HPDC, especially for the light weight design of cars with their additional casts like battery housing, conductor plate for electronics, LED-lighting, but also for general purposes of heating and cooling.

Chemical composition was optimized in order to have high conductivity (up to 30 %) compared with usual HPDC aluminum alloys and still around 10 % higher than with Silafont-36.

The specially chosen chemical composition results in following casting properties:
- excellent casting ability with good ejectability
- well usable for thin wall fins

More and more applications either in car design or in telecommunication area need also following properties:
- very good corrosion resistance to weather
- good mechanical strength compared to Al for rotors
- excellent machinability
- flangeable or deformable to fix parts together
- suitable for adhesive bonding applications
- electrical conductivity comes up to 48.5 % IACS, to substitute Cu in the idea of light weight design or Al 99.7E in rotors

**KEY FIGURES of Castasil-21**
- well usable for thin wall fins
- very good corrosion resistance to weathering
- good mechanical strength; excellent machinability
- electrical conductivity comes up to 48.5 % IACS, to substitute Cu in the idea of light weight design or Al 99.7E in rotors

# Castasil®-21 [AlSi9SrE]

RHEINFELDEN
Solutions thru Innovation

**Areas of use**

Also for all kind of casts with requirements in terms of high thermal or electrical conductivity. Conductor plate for electronics, automotive and mechanical engineering, LED-lighting, air cooling, electronic boxes or covers, E-mobil applications, inclusive electric engines.

**Chemical composition of Castasil-21 in the ingot** [% of mass]

| [%] | Si | Fe | Cu | Mn | Mg | Zn | Ti | Sr | others |
|---|---|---|---|---|---|---|---|---|---|
| min. | **8.0** | **0.5** | | | | | | **0.01** | |
| max. | **9.0** | **0.7** | 0.02 | **0.01** | **0.03** | 0.07 | **0.01** | **0.03** | 0.10 |

**Mechanical properties**

| Temper | YTS $R_{p0.2}$ [MPa] | UTS $R_m$ [MPa] | Elongation E [%] | Brinell hardness [HBW] |
|---|---|---|---|---|
| **F** | **85 – 100** | **200 – 230** | **6 – 9** | **55 – 70** |
| **O** | **80 – 100** | **170 – 200** | **9 – 15** | **55 – 65** |

**Physical data**

| Density [kg/dm³] | Coefficient of thermal expansion [1/K × $10^{-6}$] | Thermal Conductivity [W/(K × cm)] | ElectricalConductivity [% IACS] | Shrinkage [%] |
|---|---|---|---|---|
| **2.69** | **22** | **1.9** | **43.0 – 48.5** | **0.4 – 0.6** |

**KEY FIGURES of Castasil-21**

- **Very good electrical conductivity: 25 to 28 MS/m (43.0 to 48.5 % IACS) in the state O**
- **Very good thermal conductivity: 1.6 to in the state O 1.9 W/K × cm**
  Annealing of casts for the state O leads to the highest conductivities compared to other AlSi HPDC alloys.
- **Very good corrosion resistance to water and weather. Coatings are often not necessary.**

- **Very good values for the elongation at state O:** Elongation up to 15 %.
- Excellent machinable and very suitable for welding processes.
- Suitable for crimping processes.
- **Excellent castable HPDC alloy.** Solidification range, shrinkage behavior and expected die-casting mold endurance are comparable to that of AlSi9 and AlSi10Mg alloys.
- Existing die-casting cells for AlSi alloys must not be modified.
- Well suited for casts with minimum wall thickness (from 1.5 mm).
- Very low heat cracking tendency and very good release properties.

# Castasil®-21 [AlSi9SrE] – Properties

| [%] | Si | Fe | Cu | Mn | Mg | Zn | Ti | Sr | others |
|---|---|---|---|---|---|---|---|---|---|
| min. | **8.0** | **0.5** | | | | | | **0.01** | |
| max. | **9.0** | **0.7** | 0.02 | **0.01** | **0.03** | 0.07 | **0.01** | **0.03** | 0.10 |

Tab.1: Chemical composition of Castasil-21, AlSi9SrE in the ingot (in mass-%)

### Chemical composition

Table 1 shows the Castasil-21 composition with a silicon content of 8 to 9 %. Thus, the processing temperature is 680 – 750 °C, an area with typical thermal shock wear of casting chamber and cavity. Strontium causes a further lowering of the eutectic point, that is the melting temperature, of about 6 – 8 °C. In die-casting alloys Strontium reduces the affinity of the melt to the mold, i.e. the tendency to stick on, although Castasil-21 is already alloyed with an Fe content from 0.5 to 0.7 %.

As an impurity in this conductive alloy are magnesium and zinc contents of more than 0.08 % and a copper content more than 0.02 %. While forming the conductivity disturbing solid solution phases these elements are already at lower levels, but this is negligible compared to the effects from the die-casting process (Fig.1). Not so with the manganese and titanium content.

Here a value of only 0.01 % should not be exceeded in order to keep the conductivity high. Because Castasil-21 is produced with primary aluminum as base, further accompanying elements are also kept very low.

### Electrical conductivity

But more important is the modification of the silicon crystal during solidification. The strontium addition causes a coralline solidification structure of the Si crystal in the eutectic, the so called modification. The relevant Castasil-21 advantage of this modification is the higher conductivity of plus 2 – 4 MS/m.

### Heat treatment

The processing in the die-casting is characterized by a very rapid solidification. Although this achieves higher strength and hardness, this microstructure is negative for achieving high conductivity! Casts out of Castasil-21 can even further be increased in their conductivity by one-stage heat treatment, whereby the internal stress of the cast structure is equalized then. In the as-cast state a die-cast with 6 mm wall thickness may reach even 25 MS/m.

A heat treatment of 350 °C for 2 h or 250 °C for 3 h provides superior conductivity of around 28 MS/m (Fig.2). In this state, the die-casts have 83 % of the conductivity of Al99.7E. Upon the cooling of the components after the stress-relieving may only slowly air cooling to be made.

### Handling instructions

Cleaning and processing the melt should result in a low achieved oxide impurity. A strontium content of 100 to 350 ppm ensures the modification. Ingate design and die-cast parameters must be optimized to result in a solid structure without pores, due to these technically disturb the conductivity. Please look for handling instructions for details of melt preparation.

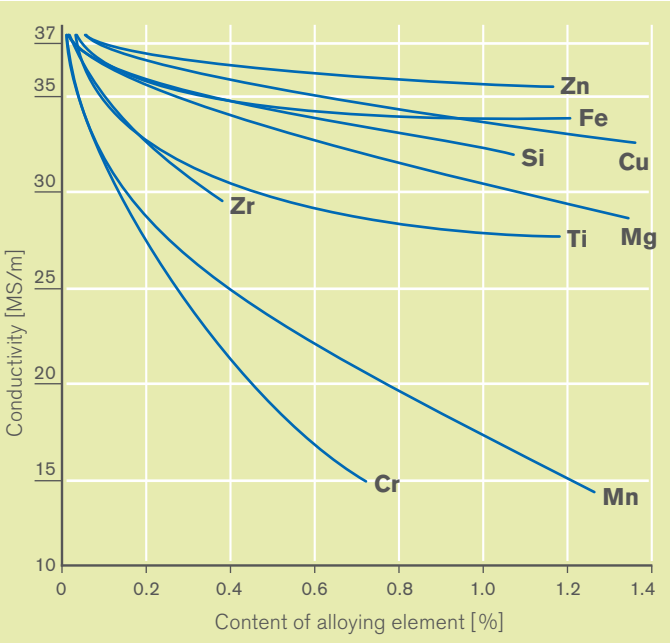



Fig.1: Relationship between electrical conductivity of Al99.9 and added alloying elements

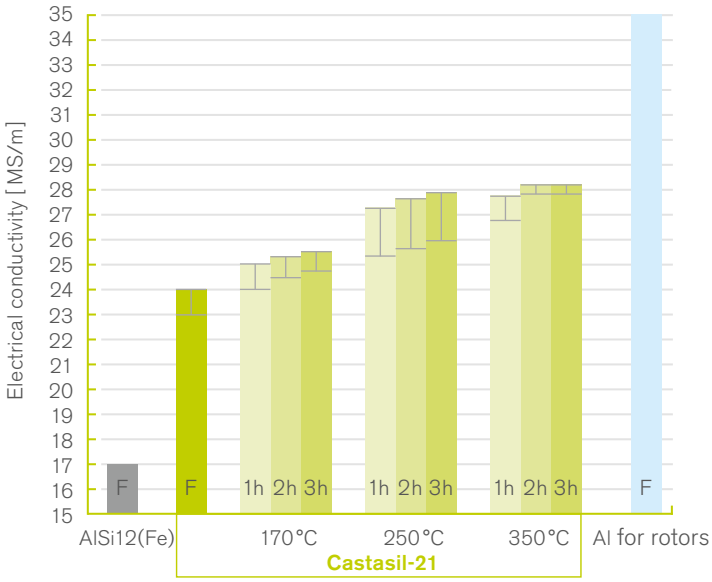
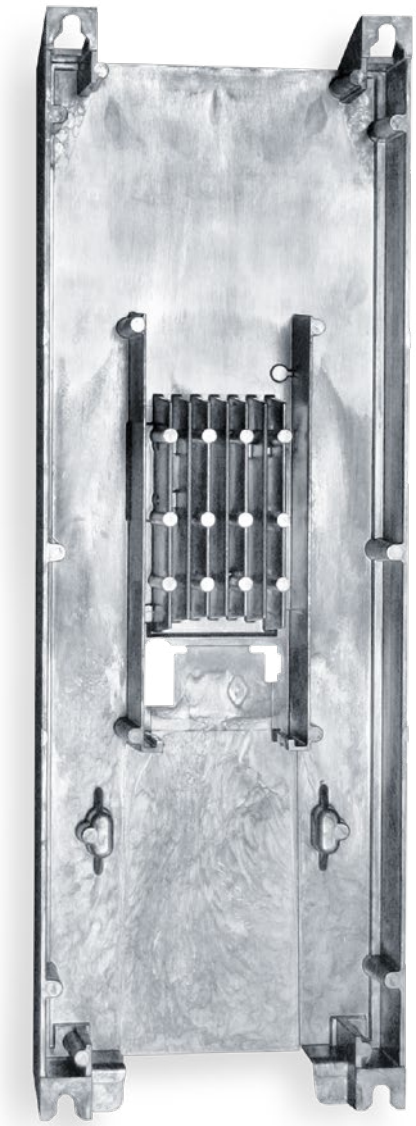
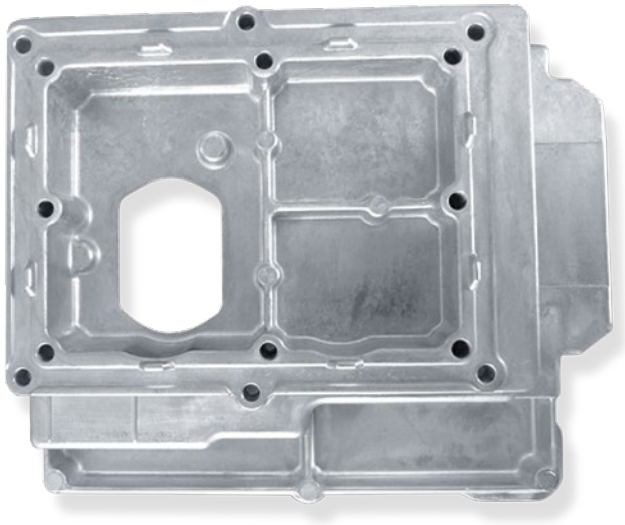



Fig.2: Electrical conductivity of Castasil-21 through heat treatment of the HPDC

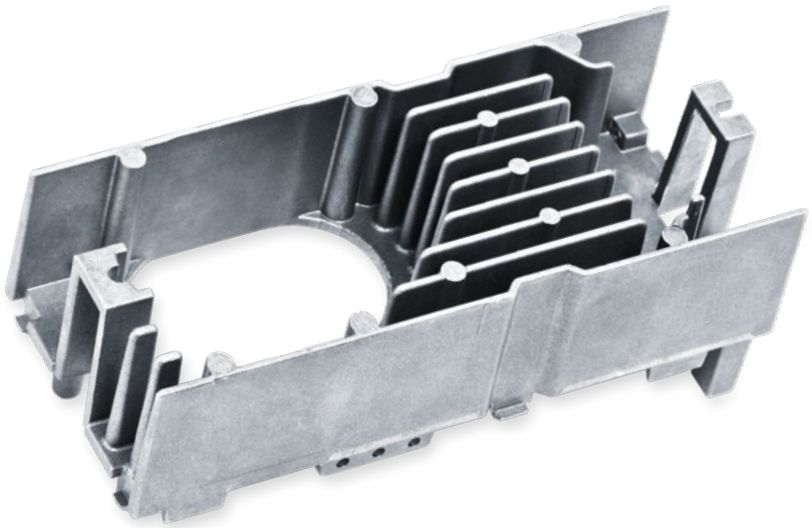
# Castasil®-21 [AlSi9SrE]



**Heatsink for electronics box**
Castasil-21; temper 0
460 × 160 × 65 mm; weight: 1.5 kg



**Heat conducting housing for switching electronics in cars**
Castasil-21; temper 0
160 × 200 × 55 mm; weight: 0.57 kg



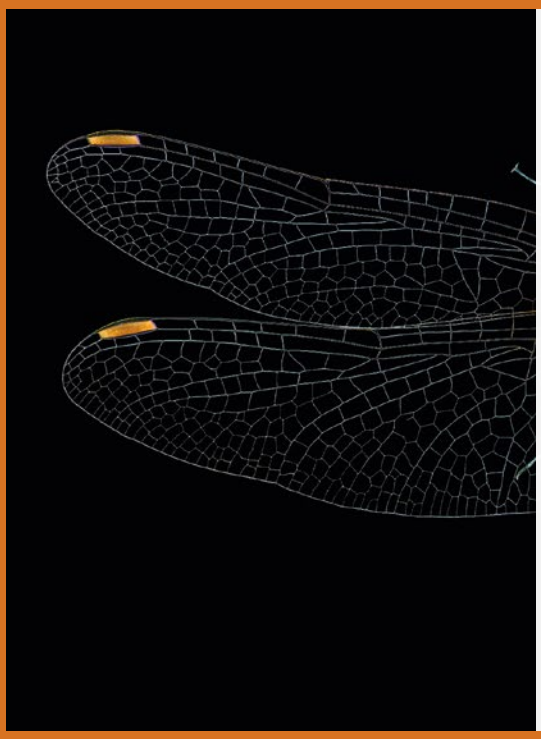
**Heatsink for electronic device**
Castasil-21; temper O
170 × 70 × 70 mm; weight: 0.4 kg

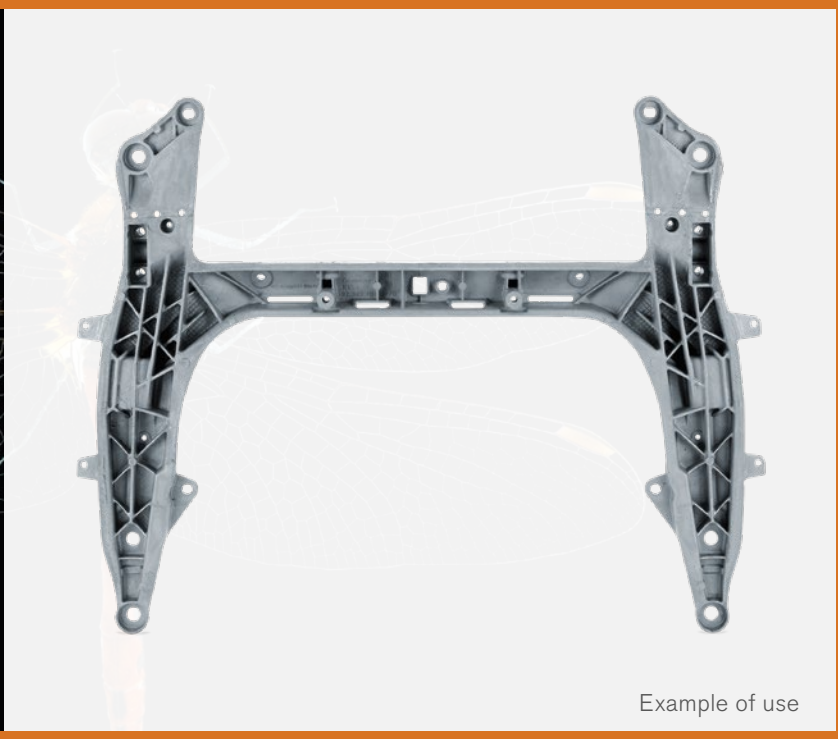
This cast with fixed electrical divice has to diffuse the hot spot of heat through the massive plate and the casted fins and should lower the maximum temperature ever.

Higher heat conductivity of the alloy results directly in lower temperature. It is not necessary to design longer fins or add forced air ventilation.

# Magsimal®-59 (Ma-59)

Of filigree lightness, but extremely resilient





Example of use

Magsimal-59 developed by RHEINFELDEN ALLOYS is a widely used HPDC alloy for automotive applications. This alloy type has excellent properties in the as-cast state, i.e. high yield strength in conjunction with high ductility. High energy absorption capacity, e.g. in the event of a crash. The fatigue strength is also higher than for conventional pressure die-cast alloys.

Most applications are therefore safety components with high performance requirements e.g. safety-belt pretensioners, steering wheel frames, crossbeams, motorbike wheel rims, control arm, suspension-strut brackets and other flap or chassis components.

The properties of Magsimal-59 depend on the wall thickness and on cooling method after HPDC. A one step heat treatment is suggested to compensate these differences and to result in up to 30% higher YTS. Air quenching would be the best, due it excludes distortions and results in high rigidity.

The alloy Magsimal-59 is produced on a primary metal basis and therefore manifests high analytical purity. This produces as a consequence outstanding mechanical strength and an excellent corrosion behavior.

Specially chosen chemical composition enables the following casting properties:

- very good castability
- suitable for minimum wall thicknesses
- low sticking to the mold
- excellent properties in the as-cast state

With increasing number of applications, mainly in car manufacturing, other properties of Magsimal-59 became also important:

- high yield strength in conjunction with high ductility
- very high energy absorption capacity
- excellent suitable for adhesive bonding applications
- very high fatigue strength
- excellent corrosion behavior
- suitable for self-piercing riveting

**KEY FIGURES of Magsimal-59**

- **high yield strength in conjunction with high ductility**
- **very high energy absorption capacity**
- **excellent fatigue strength even with sea water contact**
- **excellent corrosion behavior**

# Magsimal®-59 [AlMg5Si2Mn]

RHEINFELDEN
Solutions thru Innovation

### Areas of use

Architecture, cars, aircraft, domestic appliances, air conditioning, automotive engineering, foodstuffs industry, mechanical engineering, optics and furniture, shipbuilding, chemical industry.

### Distinguishing characteristics

HPDC alloy with excellent mechanical and dynamic properties with thin walls.
Very good weldability, suited to self-piercing riveting. Excellent corrosion resistance, excellent mechanical polishability and good machinability, ideal adhesive bonding in car body design.

### Chemical composition of Magsimal-59 in the ingot [% of mass]

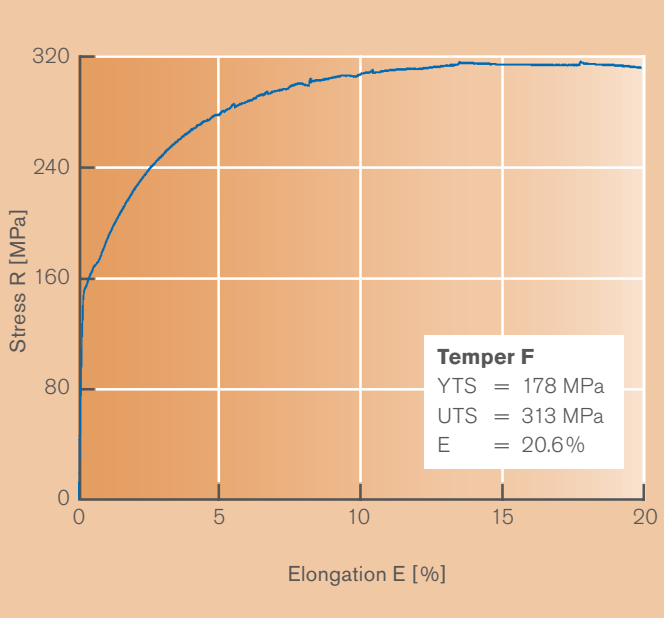
| [%] | **Si** | Fe | Cu | **Mn** | **Mg** | Zn | Ti | **Be** | others |
|---|---|---|---|---|---|---|---|---|---|
| min. | **1.8** | | | **0.5** | **5.0** | | | | |
| max. | **2.6** | 0.2 | 0.03 | **0.8** | **6.0** | 0.07 | 0.20 | **0.004** | 0.2 |

### Mechanical properties

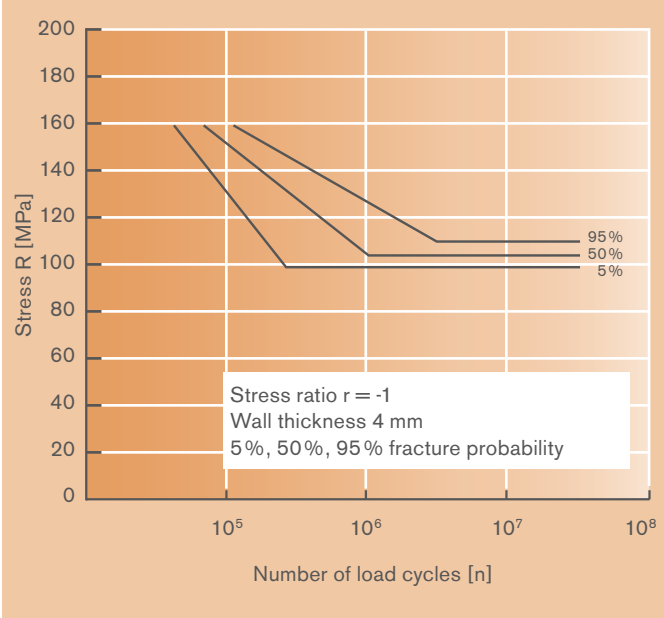
| **Wall thickness** [mm] | **YTS** $R_{p0.2}$ [MPa] | **UTS** $R_m$ [MPa] | **Elongation** E [%] |
|---|---|---|---|
| **< 2** | **> 220** | **> 300** | **10 – 15** |
| **2 – 4** | **160 – 220** | **310 – 340** | **11 – 22** |
| **4 – 6** | **140 – 170** | **250 – 320** | **9 – 14** |
| **6 – 12** | **120 – 145** | **220 – 260** | **8 – 12** |

### Physical data

| **Density** [kg/dm³] | **Coefficient of thermal expansion** [1/K × $10^{-6}$] | **Thermal Conductivity** [W/(K × cm)] | **ElectricalConductivity** [% IACS] | **Shrinkage** [%] |
|---|---|---|---|---|
| **2.63** | **24** | **1.1** | **24.0 – 27.5** | **0.6 – 1.1** |



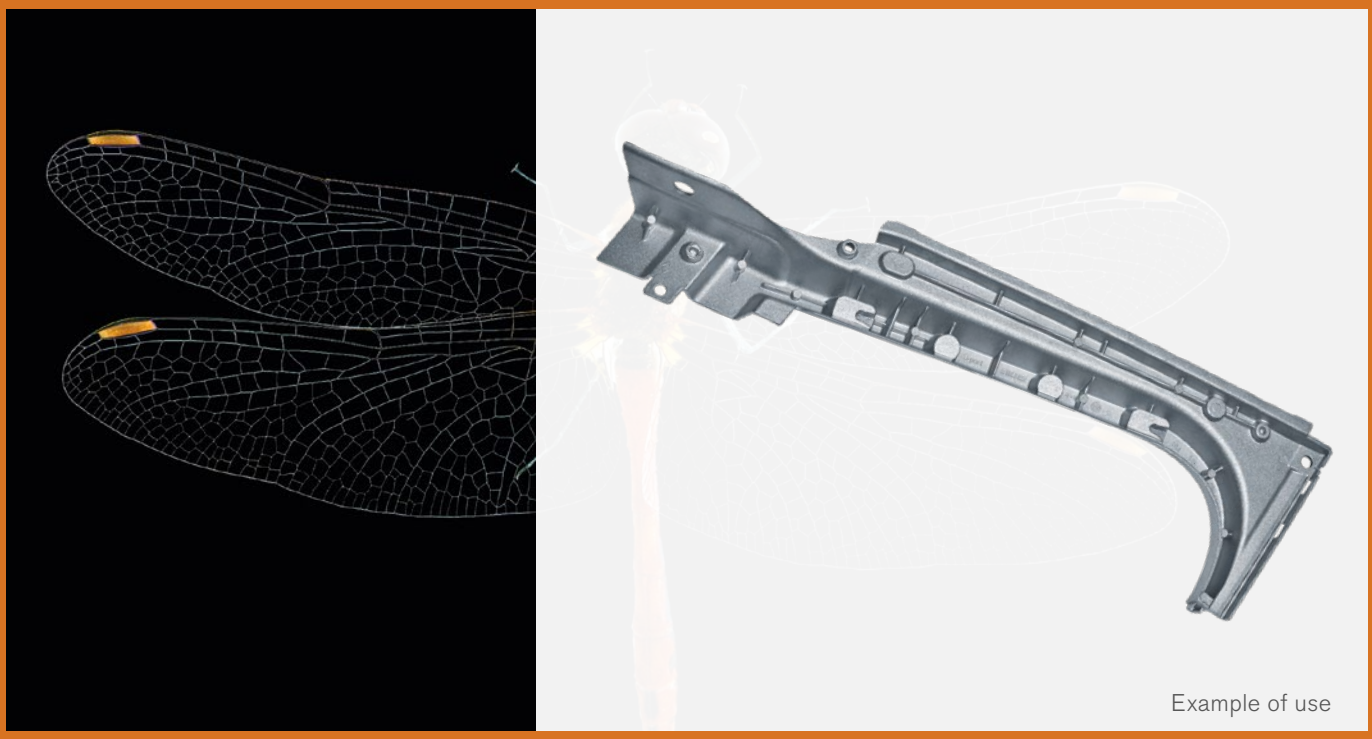

Stress-strain curve for Magsimal-59, AlMg5Si2Mn, in the as-cast state.
Wall thickness of samples: 3 mm




Wöhler's curve for Magsimal-59, AlMg5Si2Mn, in the as-cast state

# Magsimal®-plus (Ma-plus)

Of filigree lightness, but extremely resilient



Example of use

The Magsimal-plus, AlMg6Si2MnZr with an additional yield tensile strength on top to the previous Magsimal-59 was developed in the RHEINFELDEN ALLOYS TechCenter. Our aim is to get 10 % more YTS, which means 20 MPa more and may result in less wall thickness respective less weight of the cast. Compared to AlSi10MnMg this may be even 40 % advantage in strength. With this strength even steel sheet parts maybe substituted with a die-cast and its advantages for high functional integral design, ready in the as-cast state.

Despite the high Mg content of Magsimal-plus extraordinary good corrosion behavior is recognized in our tests.
The properties of Magsimal-plus depend on the wall thickness and on cooling method after HPDC. Air quenching would be the best, due it excludes distortions and results in high rigidity.

Magsimal-plus is the ultrahigh-strength AlMg die-casting alloy for high-tech lightweight construction in the vehicle structure.

- application in as-cast state for die-casts of 2 – 6 mm wall thickness
- natural hard alloy with hardening effect
- excellent corrosion resistance against salt water

**KEY FIGURES of Magsimal-plus**

- excellent yield strength in conjunction with high ductility
- no further aging effects after short term T5 treatment, e.g. paint bake cycle after powder coating
- very high energy absorption capacity
- excellent corrosion behavior
- well suitable for self-piercing riveting
- very high dynamic fatigue strengt

# Magsimal®-plus [AlMg6Si2MnZr]

RHEINFELDEN
Solutions thru Innovation

**Areas of use**

Architecture, automotive or trucks, aircraft, domestic appliances, air conditioning, automotive engineering, mechanical engineering, shipbuilding, chemical industry, substitution of complex steel sheet designs or forgings

**Chemical composition of Magsimal-plus in the ingot** [% of mass]

| [%] | **Si** | Fe | Cu | **Mn** | **Mg** | Zn | Ti | **Zr** | **others** |
|---|---|---|---|---|---|---|---|---|---|
| min. | **2.1** | | | **0.5** | **6.0** | | | **0.1** | |
| max. | **2.6** | 0.15 | 0.05 | **0.8** | **6.4** | 0.07 | 0.05 | **0.3** | **Mo; Be** |

**Mechanical properties** with 3 mm wall thickness

| **Treatment state** | **YTS** $R_{p0.2}$ [MPa] | **UTS** $R_m$ [MPa] | **Elongation** E [%] |
|---|---|---|---|
| **F** | **200 – 220** | **340 – 360** | **9 – 12** |
| **T5** | **230 – 250** | **350 – 380** | **8 – 12** |

**Physical data**

| **Density** [kg/dm³] | **Coefficient of thermal expansion** [1/K × $10^{-6}$] | **Thermal Conductivity** [W/(K × cm)] | **ElectricalConductivity** [% IACS] | **Shrinkage** [%] |
|---|---|---|---|---|
| **2.64** | **24** | **1.1** | **22.0 – 27.5** | **0.6 – 1.1** |

**KEY FIGURES of Magsimal-plus**

- **Magsimal-plus is an AlMgSi high pressure die-casting alloy with excellent mechanical properties** in the stabilized as-cast state for structural parts in the BIW of vehicles.
- The high strength of Magsimal-plus enables **very thin lightweight designs.** A weight reduction up to 40 % in comparison to an AlSi10MnMg design may be achieved.
- **No T6 or T7 heat treatment required:** Cost cutting is possible due weight reduction of the cast and due skipping heat treatment and straightening after heat treatment's distortion.
- **Excellent corrosion behavior.**

- **Advanced application range for casts in the as-cast state F.**
- Very suitable for applications in vehicle designs: Excellent **energy absorption capacity** in the event of a vehicle crash or impact to battery trays and covers.
- Substitution of complex steel sheet designs in vehicle designs is possible.
- Substitution of aluminum forgings in vehicle designs is possible.
- **Excellent weldable,** welding technique should be similar to 5000-series.
- Well suitable for self-piercing riveting, clinched joints and adhesive bonds.
- **Very high resistance to stress corrosion cracking.**

Keep in mind:

- **The casting of Magsimal-plus requires special know-how in the field of mold design, melting and casting technique.**

# Magsimal®-plus [AlMg6Si2MnZr] – Properties

| [%] | Si | Fe | Cu | Mn | Mg | Zn | Ti | Zr | others |
|---|---|---|---|---|---|---|---|---|---|
| min. | **2.1** | | | **0.5** | **6.0** | | | **0.1** | |
| max. | **2.6** | 0.15 | 0.05 | **0.8** | **6.4** | 0.07 | 0.05 | **0.3** | **Mo; Be** |

Tab. 1: Chemical composition of Magsimal-plus, AlMg6Si2MnZr in the ingot (in mass-%)

**Chemical composition**

Table 1 shows the chemical composition of an ingot for the complex alloyed Magsimal-plus, AlMg6Si2MnZr. At the die-cast, the Fe, Cu and Zn contents mentioned here as further elements may be slightly higher.

With this development, RHEINFELDEN ALLOYS offers an AlMgSi die-cast alloy with particularly high mechanical strength combined with high elongation, achievable even in as-cast condition. The Zr and Mo contents serve this purpose as well, which increase the strengthening in the as-cast state by precipitation hardening to SiZr and $Al_{12}$(Mn,Mo), shown in Fig 1.

The magnesium-silicon ratio ensures good castability and good feeding during solidification. The eutectic fraction in the microstructure is about 40 %, which is sufficient for processing into complex casts. Magnesium is present in a deliberately high surplus, based on the compound $Mg_2Si$. This is important because it must be ensured that there is no free silicon in the structure, which has negative influence to corrosion behavior. Furthermore, the targeted high-alloyed magnesium content ensures the high yield strength.

The abundant calcium and sodium found in melting flux must be kept low, as these elements generally negatively affect casting behavior and, in particular, increase the tendency of hot cracking. The phosphorus used to inert graphite must also be kept as low as possible, because this element has a particularly negative effect on the formation of the Al-$Mg_2Si$ eutectic and thus adversely affects the ductility.

Alloy melts of Al-Mg types with magnesium content above 2 % are tend to increased dross formation when the melt is hold in the furnace for a long time and the melt temperature is particularly high. Therefore, oxidation-inhibiting alloying ingredients are added to the Magsimal-plus in the range of few 0.001 % by weight. This causes the oxide skin to become denser and to oxidize less magnesium at the melting bath surface.

The thermal analysis of the Magsimal-plus is shown in Fig. 2. The temperature curve was recorded with a Quick-Cup sand crucible. The liquidus temperature is about 615 °C and the solidus temperature is about 590 °C. Here the Al-$Mg_2Si$ eutectic solidifies.

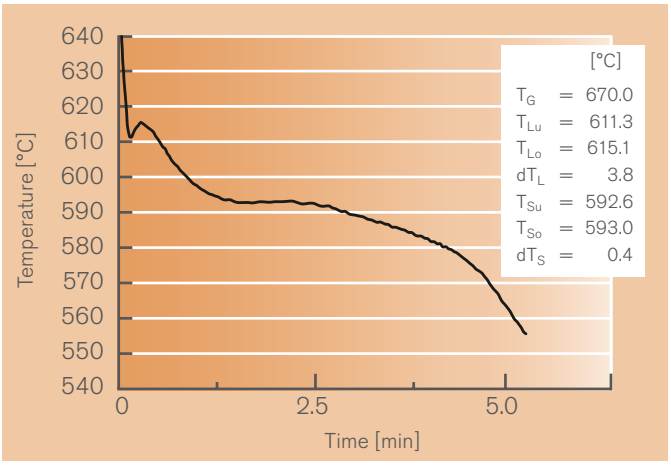



Fig. 2: Thermal analysis of Magsimal-59, AlMg5Si2Mn, in a Quick-Cup-Crucible

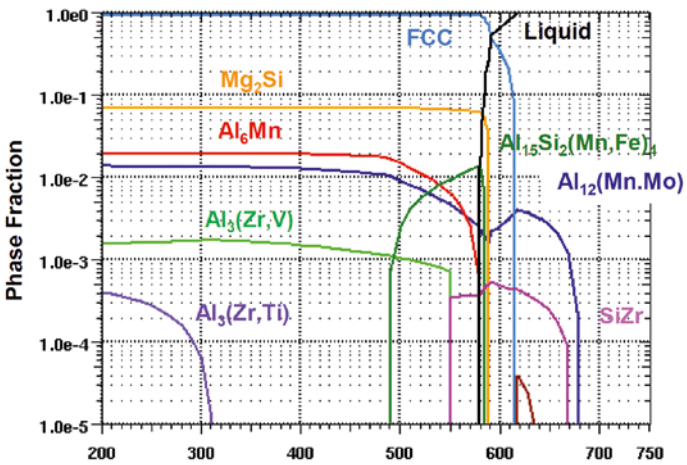



Fig. 1: Calculated phase diagram for main precipitations during solidification of Magsimal-plus, AlMg6Si2MnZr

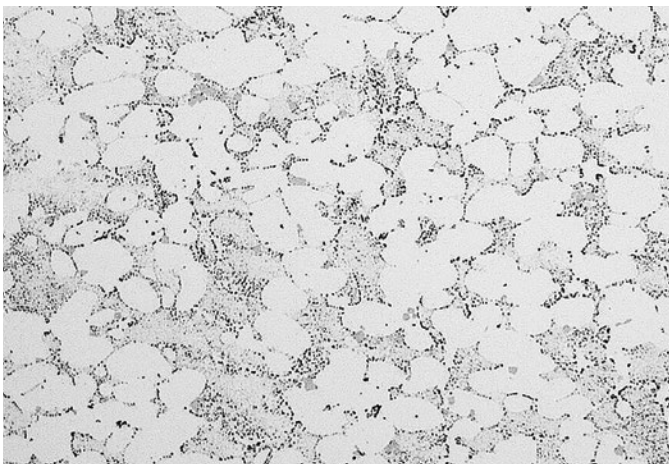


Fig. 3: Microstructure of Magsimal-plus, AlMg6Si2MnZr; 3 mm plates; magnification 1000x

The microstructure of the HPDC as shown in Fig: 3 is characterized by a uniform distribution of the $Al_6Mn$ phase. Manganese prevents sticking in the die-casting mold. Around the α-dendrites, the eutectic is distributed between α-aluminum and $Mg_2Si$. There are no coarse phases in the overview and the eutectic is very fine and spherical; therefore, this is a very ductile structure.

**Mechanical properties in the as-cast state**

For Magsimal-plus, AlMg6Si2MnZr a characteristic material property is found in the quasi-static testing of AlMg alloys. The tensile test shows small spikes in the stress-strain curve. These are not cracks in the material, but it is the so-called strain aging. This phenomenon occurs in the plastic range of the stress-strain curve. It is an interaction between dissolved atoms and migratory dislocations in the microstructure (Portevin-Chatellier effect), which leads to a very short-term and small stress drop in the stress-strain curve. Fig. 4 shows a typical example of such behavior.

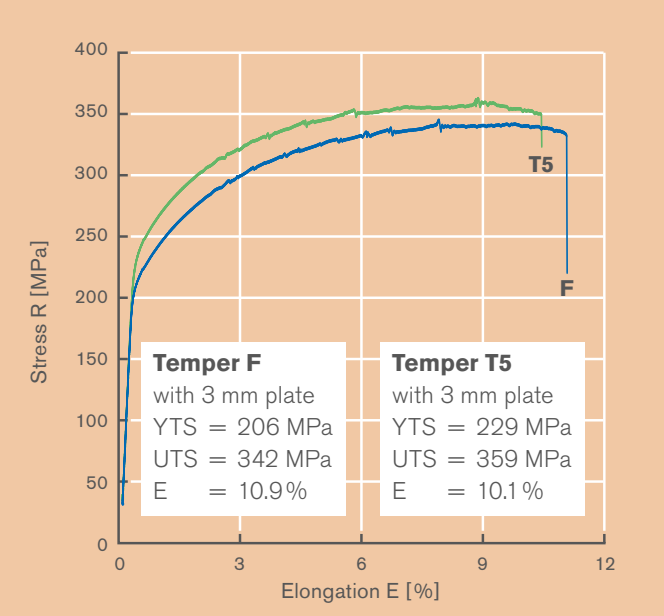



Fig. 4: Stress-strain curve for Magsimal-plus, AlMg6Si2MnZr in the as-cast state (F) and temper T5

The mechanical properties of the Magsimal-plus also depend on the wall thickness respectively on the solidification conditions.

Table 2 shows the mechanical properties in the as-cast state and after T5 heat treatment. The mechanical properties shown were determined on vacuum assisted sample plates and samples of structural die-casts with a wall thickness of 3.0 mm.
In addition, the aging at room temperature has to be considered, which occurs in thin-walled, natural hardening Magsimal-plus die-casts after demolding and water-quenching.

Only after 20 days or after T5 treatment is the yield strength at a stable, higher level. For water-quenched casts, the strength increases by about 30 MPa, but with the use of air quenching by only 5 MPa higher. However, the elongation at break barely decreases.

It must be noted that the values in the real cast may vary depending on the proportion of pre-solidification and oxide contents as well as the flow and solidification behavior during cavity filling and are generally better in well-flowed cast cross-sections than in areas of cavity filling end. By connecting overflows and vents at correct positions this influence can be reduced. Therefore, the determination of suitable positions for the removal of test specimens from die-casts is demanding and must be defined in any case exactly between the foundry and the die-cast part designer.

| Casting Method | Wall thickness | Numbers of test pieces | Treatment state | YTS $R_{p0.2}$ [MPa] | UTS $R_m$ [MPa] | Elongation E [%] |
|---|---|---|---|---|---|---|
| **TechCenter** | **3 mm** | **40** | **F** | **208** | **348** | **10.4** |
| Standard deviation | | | | 2.8 | 6.5 | 1.4 |
| **TechCenter** | **3 mm** | **40** | **T5** | **231** | **363** | **10.0** |
| Standard deviation | | | | 2.9 | 6.5 | 1.4 |
| **Testpart** | **3 mm** | **36** | **T5** | **239** | **366** | **10.2** |
| Standard deviation | | | | 10.9 | 9.5 | 2.8 |

Tab 2: Average mechanical properties of Magsimal-plus, AlMg6Si2MnZr in the as-cast state and after T5 from test plates and typical HPDC parts

# Magsimal®-plus [AlMg6Si2MnZr] – Properties

**Mechanical properties after T5 treatment**

A further increase in strength can be achieved by a T5 treatment of the cast at only 200 °C in 30–60 minutes. It has been indicated that the cast must be quenched immediately after demolding from the die-casting mold, so that the appropriate increase in strength during artificial ageing can be achieved. Only a cooling in air after demolding does not achieve the full effect.
The increase in mechanical properties compared to the as-cast state is shown in Fig. 4. These mechanical properties were determined on 3.0 mm sample plates as well as on large-sized structural die-casts, designed and manufactured to suit the alloy features.
This short T5 artificial aging treatment thus significantly shortens the otherwise waiting for natural aging.

In the automotive industry also demands on the short and long term stability of the mechanical properties are made. Such aging tests at 205 °C for 1 h or 150 °C for 1000 h, the casts from Magsimal-plus has been successfully passed after short T5 treatment.

**Weldability**

All-aluminum constructions with structural cast application are virtually impossible without welded joints. Therefore, butt welds and fillet welds were tested with die-casted sample plates in the MIG process, shown in Fig 5a. The Magsimal-plus die-cast sample plate with 3.0 mm thickness was butt-welded to AlMgSi0.5.
The welding filler material used was an S-AlMg4.5Mn welding wire with Ø 1.2 mm.

The MIG pulse synergic welding machine TPS-400i from Fronius was used with a pulsed arc process with controlled material transition. Thus, the workpiece surface is preheated and achieved an accurately metered current pulse for the targeted detachment of a welding material drop. This Cold-Metal-Transfer principle guarantees very low-spatter welding. The particular advantage of this connection welding is also the only slight distortion in particularly thin-walled produced Magsimal-plus die-casts. Both, outer appearance and inner weld quality were achieved with very good results (Fig. 5b).

Another subordinate factor is that the Magsimal-plus, unlike classic AlSiMg alloys, has virtually no hysteresis in the linear expansion when heated to 300 °C. It is therefore barely expected component distortion after such heat in the environment of the weld.

**Corrosion resistance**

AlMg alloys are usually very resistant to corrosion and are therefore also used in a seawater-containing atmosphere.
Since this type of alloy can also be used for structural casts in vehicle construction, a test for determining the tendency to stress corrosion cracking is inevitable.

Corrosion resistance was tested with an intercrystalline corrosion test according to ASTM G110-92 and a salt mist spray test according to EN ISO 9227 and was passed with very good results.

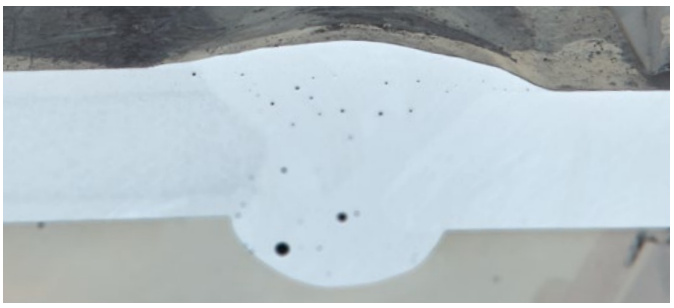


Fig. 5a: Cross-section of a butt-welded cast-sheet-connection

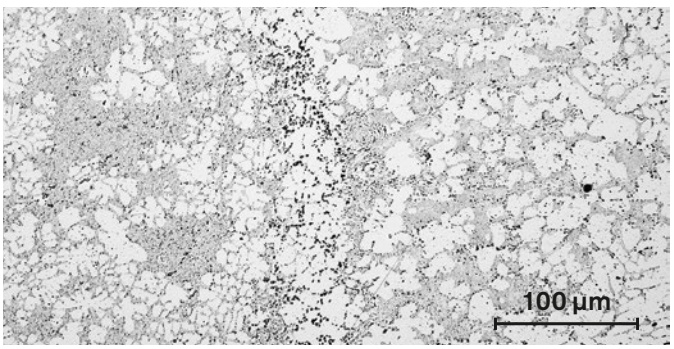



Fig. 5b: Micrograph from the welding beam section between Magsimal-plus and AlMgSi0.5 sheet

Fig. 6a: Overview about the punch rivet tests with Magsimal-plus, AlMg6Si2MnZr

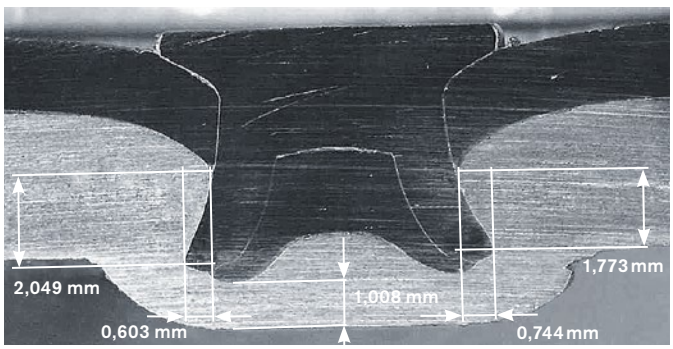



Fig. 6b: Cross-section of the punch rivet with some calculations

**Riveting capability**

In body construction with its various materials, the connection technology punch riveting plays a major role (Fig. 6a). In this process semi-hollow punch rivets pierce the overhead steel or aluminum sheet and dig into the cast (Fig. 6b).
The casting material must be able to withstand the deformations on the closing head of the riveting mold. A further evaluation is carried out at closely side by side placed rivets or with rivets placed close to the cast' edge in the demand for crack-free closing heads on the casted surface.

The rivet mold significantly influences the riveting result. The semi-hollow punch riveting processes have to be optimized for high-strength Magsimal-plus applications. Sections of the cast intended for punch riveting should not be designed thinner than 3 mm to have the required ductility.

**Surface finishing**

Magsimal-plus can be painted, powder-coated, polished or anodized. Polishing results into a typical slight blue coloration of the surface gloss. When anodizing, it should be noted that a gray shade should be formed because of the low silicon content. For decorative purposes, it is therefore advisable to use a chrome layer or the polished surface.

**Melting process**

Magsimal-plus has a special long-term grain refinement particularly affecting the Al-$Mg_2Si$ eutectic. The degree of fineness of the eutectic determines the elongation respectively the toughness of the cast (Fig. 7a). Special alloying elements in alloy production greatly reduce the oxidation of the melt, which is particularly characteristic to AlMg alloys. Agglomerations of oxides on bath surfaces and on the bottom of the furnace are barely formed. After rapid melting of the ingots a melt cleaning with a gas rotor have to be carried out. The properties of Magsimal-plus are retained if no sodium-containing treatment fluxes, no grain refining and modification agents, no phosphorus, alkali and earth alkali containing substances and no different metals are supplied to the melt. Because of this, the Al-$Mg_2Si$ eutectic is strongly influenced and coarsened (Fig. 7b).

The temperature during Magsimal-plus melting should not permanently exceed 780 °C. The holding temperature after melting should be set to 760 °C.
In melting furnaces, which keep the melt moving with heat convection, the form of lids are reduced by less oxide-melt reactions and segregations. This also applies to furnaces in which the bath movement takes place by means of rotor or with purge gas initiation by furnace bottom stones. Furnaces with roof heating and no bath movement cause difficulties for longer holding time. Melting of all aluminum alloys and also Magsimal-plus reacts less with the refractory material, if it contains more than 85 % aluminum oxide.

The remelting of runners, return scrap and others is not a problem. However, care must be taken that mixing with other alloys cannot take place. This would negatively affect the mechanical properties.
When using return material, a good melt cleaning by means of rotor and argon or nitrogen gas is absolutely necessary, since oxide inclusions, oxide skins, etc. have to be removed. These can accumulate in the melting and casting process and exert a negative influence both on the cast properties and on the achievable mechanical characteristics.
The resulting dross after cleaning and degassing cycle can be reduced in their metal content with use of sodium-free dross treatment flux.

**Casting process**

For further information, please refer to the information on the processing of AlMg casting alloys in the die-casting process in the Chapters on Castaduct-42 alloy and design guidelines for casts and die-casting molds.

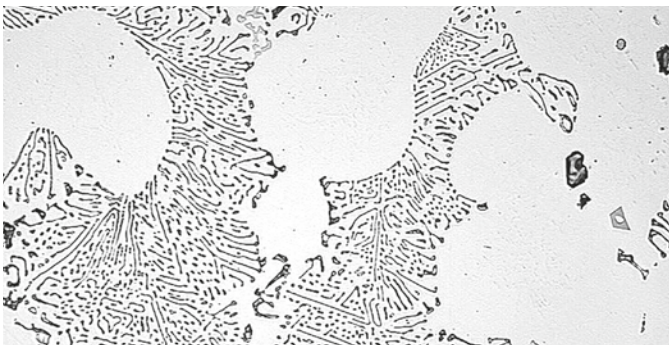


Fig. 7a: Fine Al-$Mg_2Si$-eutectic of Magsimal-plus, AlMg6Si2MnZr

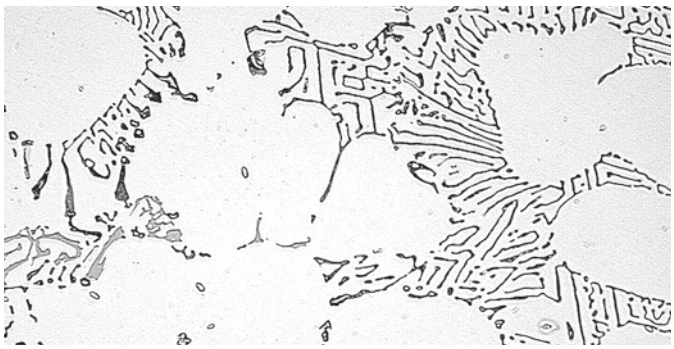
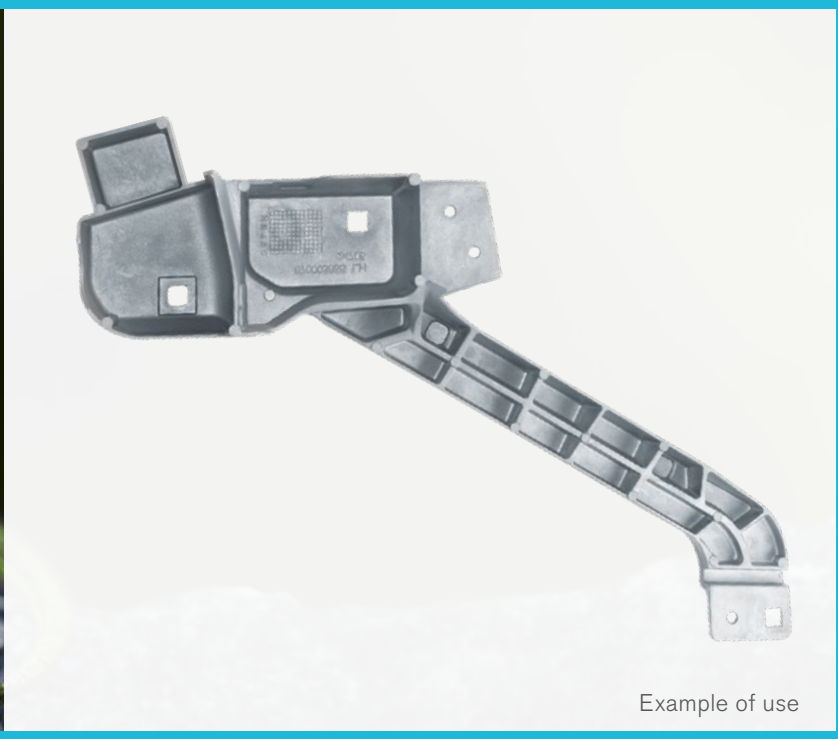


Fig. 7b: Coarse Al-$Mg_2Si$-eutectic

# Castaduct®-42 (Cc-42)

Always fascinating pliable down to the finest detail



Example of use

The Castaduct-42 from the AlFeMg alloy family, newly developed in the RHEINFELDEN ALLOYS TechCenter, amazes both the foundry industry and the automotive industry: Highest elongation in the as-cast and non-heat treated condition, along with a yield strength just achieved with well-known AlSi10MnMg cast alloys with a T7 two-stage heat treatment.

The good castability in the die-casting process enables the production of large and thin-walled structural cast components. Castaduct-42 can be combined with other materials in many ways using a variety of established joining techniques.

Castaduct-42 is plain and robust in its alloy composition, based on the two alloy components Fe and Mg. The carefully co-ordinated alloy components of Castaduct-42 enable an easy handling in the die-casting process.
Any melt addition is completely eliminated.

The high Fe content in the Castaduct-42 ensures reduced sticking tendency and improved die-casting mold life.

The Castaduct-42 is a natural-hard alloy and exhibits excellent long-term stability in the as-cast state, even at high application temperatures.
The corrosion resistance of Castaduct-42 is excellent. Further protection and di-electric strength may come with anodizing.

Next to the applications for structural cast components, thus the ductile Castaduct-42 also is very suitable for general use in the e-mobility: battery cases and trays, cases and covers for electronic components of the high-voltage technology.

**KEY FIGURES of Castaduct-42**

- very suitable for lightweight construction
- highest ductility in the as-cast state
- excellent corrosion resistance
- very well suited for established connection techniques in vehicle construction

# Castaduct®-42 [AlMg4Fe2]

RHEINFELDEN
Solutions thru Innovation

**Areas of use**

Large and thin-walled structural casts; connection nodes for space frame designs; battery housings, electronic covers or shelter housings; thin-walled body parts; for architecture, cars, lighting, aircraft, domestic appliances, air conditioning, automotive engineering, foodstuffs industry, mechanical engineering, shipbuilding, defense engineering.
Replaces typical AlSi10MnMg high pressure die-casts with O/T4/T7 treatment, but also Magnesium-based HPDC.

**Chemical composition of Castaduct-42 in the ingot** [% of mass]

| [%] | Si | **Fe** | Cu | Mn | **Mg** | Zn | Ti | **others** |
|---|---|---|---|---|---|---|---|---|
| min. | | **1.5** | | | **4.0** | | | |
| max. | 0.2 | **1.7** | 0.2 | 0.15 | **4.6** | 0.3 | 0.2 | **Be** |

**Mechanical properties**

| **Treatment state** | **Wall thickness** [mm] | **YTS** $R_{p0.2}$ [MPa] | **UTS** $R_m$ [MPa] | **Elongation** E [%] | **Brinell hardness** [HBW] |
|---|---|---|---|---|---|
| **F** | **2 – 4** | **120 – 150** | **240 – 280** | **10 – 22** | **65 – 75** |

**Physical data**

| **Density** [kg/dm³] | **Coefficient of thermal expansion** [1/K × $10^{-6}$] | **Thermal Conductivity** [W/(K × cm)] | **ElectricalConductivity** [% IACS] | **Shrinkage** [%] |
|---|---|---|---|---|
| **2.69** | **25** | **1.4** | **26.0 – 29.5** | **0.5 – 0.9** |

**KEY FIGURES of Castaduct-42**

- **Castaduct-42 is an easy to handle alloy for BIW parts like structure casts.**
- **Innovative and plain alloy composition.**
  Developed on base of AlFe-eutectic composition.
- **No T5, T6 or T7 heat treatment required:**
  Cost cutting is possible due skipping heat treatment and straightening of distortion.
- **Excellent resistance to sea water atmosphere.**

- **Excellent suitable for BIW automotive structural applications** with requirements of medium strength, but highest deformability.
- High percentages of in-house scrap can easily be remelted.
- **Easy melt preparing without any modifying or grain structure treatment.**
- **Very low sticking behavior in the mold,** due the high Fe-content.
- **Easy castability in HPDC process,** moderate casting temperature, low tendency for pre-solidifications and hot cracks.
- **High resistance against high temperature ageing,** up to 350 °C no influence to the mechanical strength at RT.
- **Well suitable for self-piercing rivets, clinched joints and crimping.** High values of deforming in a bending test are constantly measured. Much better than with AlSi10MnMg in the as-cast state.
- **Well weldable,** with welding technique similar to 5000-series.
- **Very well suitable for anodizing,** due to the low Silicon content a bright surface image may be achieved.
- **Well suitable for adhesive bonds.**

Keep in mind:

- **The casting of Castaduct-42 requires special know-how in the field of mold design, melting and casting technique.**

# Castaduct®-42 [AlMg4Fe2] – Properties

| [%] | Si | **Fe** | Cu | Mn | **Mg** | Zn | Ti | **others** |
|---|---|---|---|---|---|---|---|---|
| min. | | **1.5** | | | **4.0** | | | |
| max. | 0.2 | **1.7** | 0.2 | 0.15 | **4.6** | 0.3 | 0.2 | **Be** |

Tab.1: Chemical composition of Castaduct-42, AlMg4Fe2 in the ingot (in mass-%)

**Chemical Composition**

The Castaduct-42 high pressure die-casting alloy is simple and robust in its alloy composition, based on the Al-Fe-Mg eutectic in hypereutectic composition of the two alloying components Fe and Mg. Iron is present in a necessary high content of about 1.6%. The magnesium content is about 4.3%.

For Castaduct-42, the Mg content should not fall below 4.0% and should not exceed 4.6%. This is easy to handle at the melting and casting plant because the Mg content need not be precisely controlled and not set to tolerances of less than 0.05% by weight.
Also, a modification of the eutectic phases is omitted in this type of alloy. The elimination of silicon as an alloying element eliminates any $Mg_2Si$ precipitation hardening, i.e. the Castaduct-42 is naturally hard and has an excellent long-term stability even at higher temperatures.

**Influence of Iron**

Fig.2 shows the calculated constitutional diagram of Castaduct-42, AlMg4Fe2 with an given Mg content of 4.5%. The Mg is dissolved under HPDC conditions in the primary solidifying Al-phase. Al solidifies in dendritic shape.
The liquidus temperature in this Al-Fe-Mg eutectic is lowered to 629°C, the solidus temperature is 580°C.
The micrographs in Fig.1a and 1b show the finely formed Al-Fe eutectic. The overview shows the large proportion of the eutectic. This ratio of eutectic to α-Al dendrites and the low processing temperature lead to the good casting properties.

The Fe content of the casts in Castaduct-42 should be kept between 1.3% and 1.7%. Thus, the hypereutectic alloy system is formed with the precipitation of $Al_{13}Fe_4$. Higher levels lead to the formation of large and plate-like Fe-containing phases also under pressure casting conditions, which reduce the elongation. This also occurs at slower solidification rates, comparable to sand casting process.

A heat treatment leads to no change in the phases and can therefore be omitted.

The tendency of Castaduct-42 to adhere to the mold is substantially reduced by the Fe content compared to low-Fe structural casting alloys. In practice, the dissolution behavior of steel in the Castaduct-42 melt was halved in immersion tests.
Higher mold endurance is expected and long flow paths can be achieved with small wall thicknesses.

**Disturbing elements of the in Castaduct-42 alloy**

However, the fine structure of the Al-Fe eutectic can only be maintained if the Si content is kept below 0.2%. Even slightly higher Si contents form notch-active AlSiFe phases, which result in a reduction in elongation.

Also Mn contents should remain low alloyed to avoid coarse and unfavorable solid solution phase precipitations.
Calcium and sodium worsen castability and cause increased hot cracking tendency and reduced elongation at break. Therefore, melting fluxes should be used specifically for AlMg alloys.

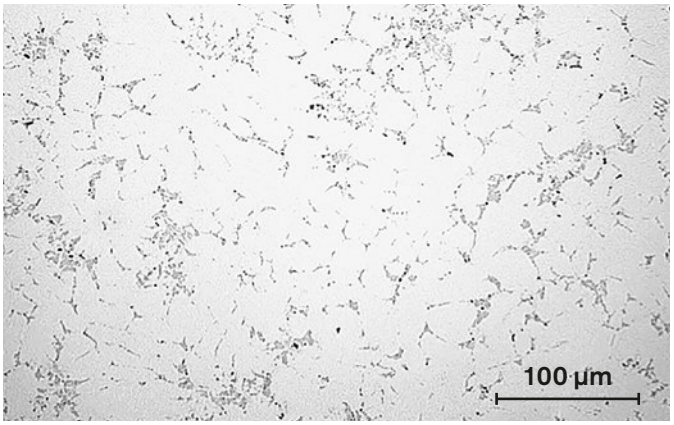



Fig.1a: Microstructure of Castaduct-42, AlMg4Fe2 in the as-cast state, 3 mm sample plate

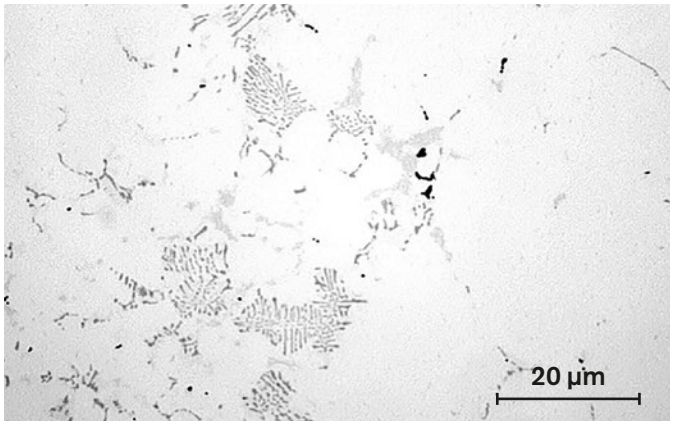



Fig.1b: Magnification of the Al-Fe-eutectic in the microstructure of Castaduct-42, AlMg4Fe2

### Influence of Magnesium

The Mg content determines the strength of Castaduct-42. The Mg content increases the strength in as-cast condition by 60 MPa compared to the binary AlFe alloy. The Mg is always dissolved in α-Al-phase, but may be present in slightly different concentrations.
A more Mg leads to higher yield strength, but also to a smaller elongation. A balance of mechanical properties is achieved at 4.2 % to 4.5 %.

A possible increase in the sensitivity for stress corrosion cracking is only present above 5 % Mg content. On the other hand, a sufficiently high Mg content should allow the hypereutectic character and thus the good casting capability.

Alloy melts of Al-Mg types with magnesium content above 2 % are tend to increased dross formation when the melt is hold in the furnace for a long time and the melt temperature is particularly high. Therefore, the Castaduct-42 oxidation-inhibiting alloying ingredients are added in the range of few 0.001 % by weight. This causes the oxide skin to become denser and to oxidize less magnesium at the melting bath surface.

### Mechanical properties

The Castaduct-42 stress-strain diagram in Fig. 3 clearly illustrates the potential of this casting alloy. With favorable casting conditions, i.e. a die-casting process tailored to this type of alloy, even better yield strength characteristics can be achieved in conjunction with an elongation of up to 22 %.

For Castaduct-42 a characteristic material property is found in the mechanical testing of AlMg alloys. The tensile test shows small spikes in the stress-strain curve. These are not cracks in the material, but it is the so-called strain aging. This phenomenon occurs in the plastic range of the stress-strain curve. This Portevin-Chatellier effect is an interaction between dissolved atoms and migratory dislocations in the microstructure, which leads to a short-term and small stress drop in the stress-strain curve. Fig. 3 shows a typical example of such behavior.

### Influence of wall thickness

In the area of common die-cast wall thicknesses from 2 to 4 mm, the Castaduct-42 shows only minor variations in the mechanical characteristics.

Tab. 2 shows the mechanical properties in the as-cast state F. The mechanical properties shown were determined on vacuum supported HPDC sample plates with 2.0 mm wall thickness.
As part of testing Castaduct-42 with real structure casts, yield tensile strengths of between 120 and 150 MPa, ultimate tensile strengths of between 240 and 280 MPa and elongations at break of 10 to 22 % were measured on tensile specimens with a wall thickness of 2–4 mm.
It must be noted that the values in the real cast may vary depending on the proportion of pre-solidification and oxide contents as well as the flow and solidification behavior during cavity filling and are generally better in well-flowed cast cross-sections than in areas of cavity filling end. By connecting overflows and vents at correct positions this influence can be reduced. Therefore, the determination of suitable positions for the removal of test specimens from die-casts is demanding and must be defined in any case exactly between the foundry and the die-cast part designer.

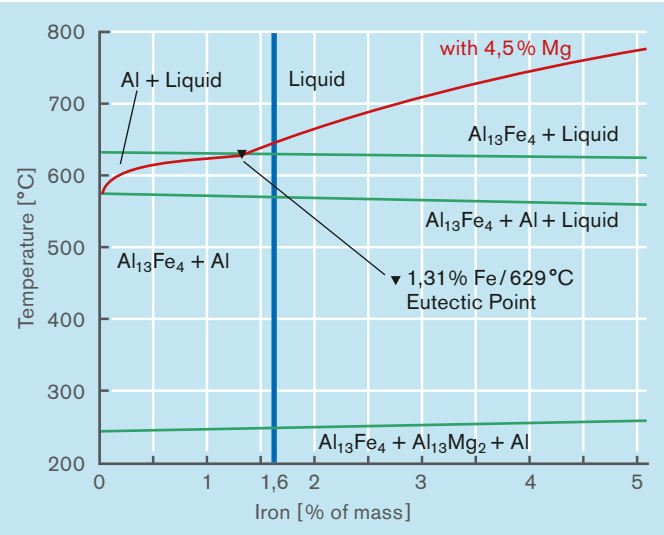



Fig. 2: Constitutional diagram of Castaduct-42, AlMg4Fe2 with 4.5 % Mg

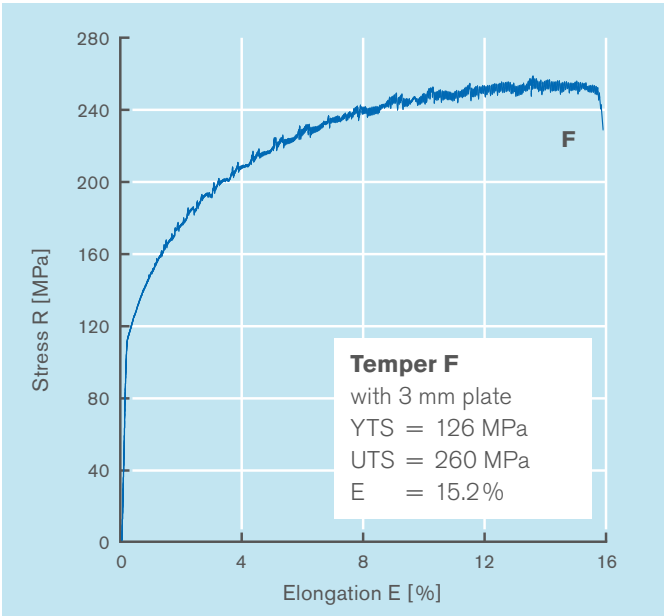



Fig. 3: Stress-strain curve of Castaduct-42, AlMg4Fe2 determined from 3.0 mm flat tensile specimen

# Castaduct®-42 [AlMg4Fe2] – Properties

| Treatment state | Wall thickness [mm] | YTS $R_{p0.2}$ [MPa] | UTS $R_m$ [MPa] | Elongation E [%] | Brinell hardness [HBW] |
|---|---|---|---|---|---|
| F | 2–4 | 120–150 | 240–280 | 10–22 | 65–75 |

Tab 2: Mechanical properties of Castaduct-42, AlMg4Fe2 in the as-cast state; the typical wall thickness of the several tested HPDC are 2–4 mm

**Deformation capability**

The Castaduct-42 alloy has a very high deformability in as-cast condition and is thus also well suited for crash-relevant applications in vehicle design. The evidence was provided in the context of alloy development by means of plate bending test for metallic materials, according to VDA 238–100 (Fig. 4) and with Erichsen cupping tests and confirmed several times by samples of real casts. Plate bending angles of up to 60° are achieved. Bending angles of more than 70° could be achieved with proper casting conditions. These high measurement values indicate a very good behavior in punch riveting and similar joining methods.

The Erichsen cupping test is another test for the suitability of a casting alloy for structural components in vehicle design. Here, a sheet-like test strip from the cast is deliberately deformed to a point of first fissure by a ball lowering in the measurement setup. With increasing sample plate thickness the Erichsen depression decreases. For a 2.0 mm sample plate in AlSi alloy deformation values around 3 mm are common. For the same sample plate in Castaduct-42 the values of 4.5 mm are very high and indicate a high deformation capacity in the event of a crash.

In the context of alloy development, a hudge amount of punching tests were carried out with very good results on 3.0 mm sample plates and on samples of real Castaduct-42 casts (Fig. 5a/5b).

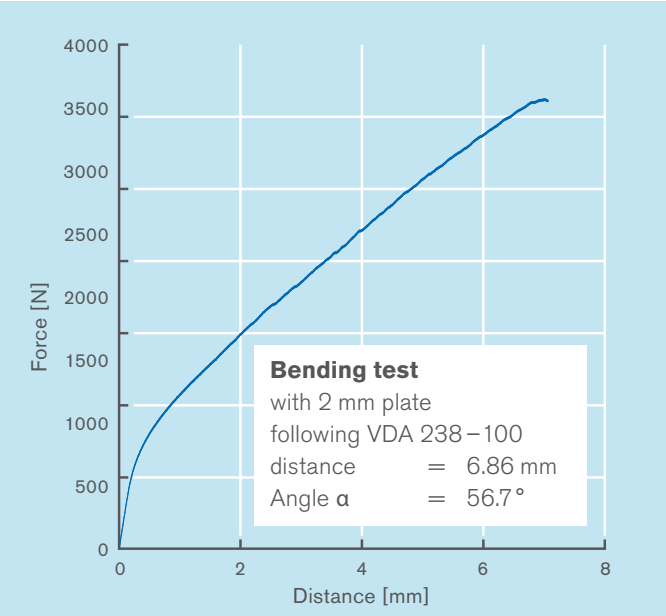



Fig. 4: Load-extension diagram of plate bending test Castaduct-42 , AlMg4Fe2

Castaduct-42 was always tested in as-cast condition and showed very good results.

**Welding performance**

In addition to the very good punch riveting ability, a good degree of welding suitability is of great importance for the use of Castaduct-42 in vehicle design.

In the MIG process, Castaduct-42 die-cast sample plates 3.0 mm were butt-welded and fillet-welded to AW-AlMgSi0.5 to test the weldability (Fig. 6a/6b). The welding filler material used was an S-AlMg4.5Mn welding wire with Ø 1.2 mm.
The micrographs of the welded seams show a low-pore and finely structured microstructure, which results in homogeneous material properties in the joining zone. The silicon free welding conditions leads here to no significant changes in the mechanical characteristics. The right choice of welding filler material leads to crack-free and ductile welds.

For welded joints on aluminum sheets of the 6000 series, i.e. AlMgSi alloys, the alloy S-AlMg4.5Mn is also recommended as the welding filler material.

Fig. 5a: Rivet tests connecting steel sheet to HPDC in Castaduct-42, AlMg4Fe2

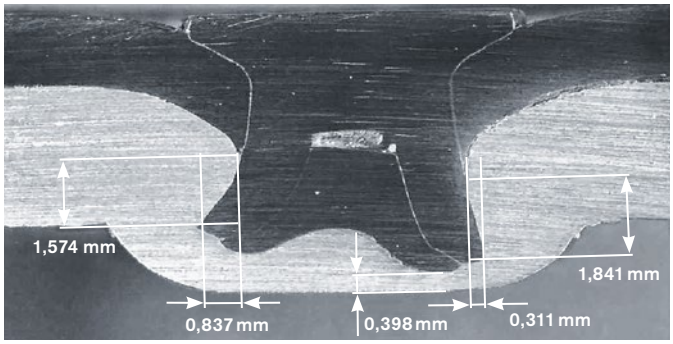



Fig. 5b: Crossection with calculation of the HSN rivet test in Castaduct-42, AlMg4Fe2

### Corrosion resistance

Corrosion resistance was tested with an intercrystalline corrosion test according to ASTM G110-92 and a salt mist spray test according to EN ISO 9227.
In the intercrystalline corrosion test, the samples are aged for two hours at room temperature in a hydrochloric acid test solution with 1000 ml $H_2O$, 20 g NaCl and 100 ml HCl 25 %. For the salt mist spray test, the samples were exposed to a defined salt mist load for 14 days.

| Casting alloy | IC max. depth [µm] | | Salt spray max. raid [µm] | |
|---|---|---|---|---|
| | Surface | End wall | Depth | Diameter |
| Castaduct-42 | 135 | 90 | 15 | 200 |
| Castasil-37 | 235 | 205 | 150 | 2400 |

The corrosion resistance of the alloys Silafont-36, AlSi10MnMg and Castasil-37, AlSi10MnMoZr is generally considered to be well-suited for structural cast applications in vehicle design. The corrosion resistance of the Castaduct-42 alloy can be estimated as very well-suited for automotive applications.

### Thermal conductivity

The thermal conductivity of Castaduct-42 was measured on die-casted sample plates in the as-cast state F with a thickness of 2.0 mm. The samples were heated in 50 °C increments at 10 °C/min from 20 °C to 500 °C and back again. The conductivity measurement was carried out after a holding time of 60 min each increment (Fig. 7).

The Castaduct-42 shows itself here with a averaged value of 140 W/(m × K) clearly unaffected by the heat input. A heat treatment would thus lead to any changes in the thermal conductivity and is primarily due to the absence of silicon.

### Heat treatment

The Castaduct-42 is a naturally hard die-casting alloy and does not require any heat treatments, since no hardening structural components are present. Stabilization annealing is not required. Even an annealing temperature up to 350 °C results in no influence on the cast structure or the mechanical properties after cooling.

### Short-term stability / Long-term stability

Castaduct-42 has excellent aging resistance and excellent dimensional stability, which is due to the Si-free alloy composition. Both the tests of the short-term stability with 1h / 205 °C and the tests of long-term stability with 1000 h / 150 °C have been repeatedly successfully passed.

Fig. 6a: Cross-section of a welded cast-sheet-connection in Castaduct-42, AlMg4Fe2

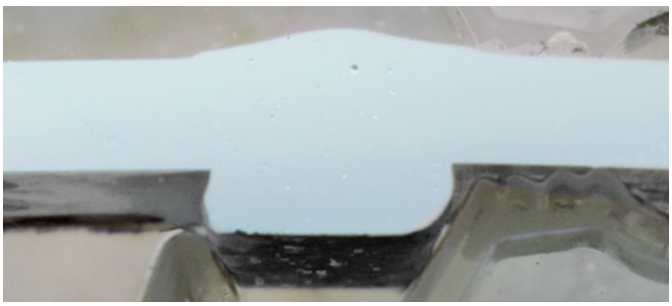


Fig. 6b: Overview from the welding beam section between Castaduct-42, AlMg4Fe2 and AW-AlMgSi0.5; filler material S-AlMg4.5Mn

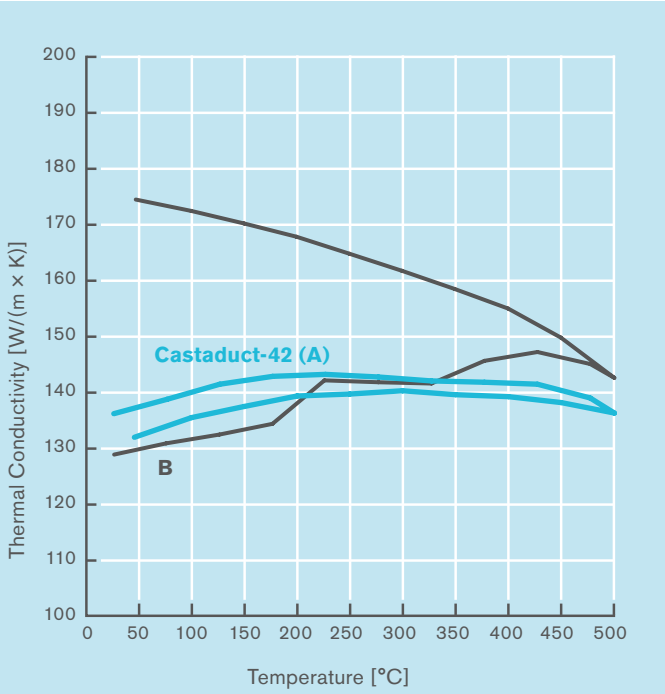



Fig. 7: Determination of the thermal conductivity of Castaduct-42, AlMg4Fe2 (A) compared to Silafont-38, AlSi9MnMgZn (B)

# Castaduct®-42 [AlMg4Fe2] – Properties

**Dimensional stability**

For proof of the excellent dimensional stability of Castaduct-42 after heating, a dilatometer curve was prepared (Fig. 8). For this purpose two die-casted sample plates were tested. The expansion was 0.44 % for 20 °C to 200 °C and corresponds to a thermal expansion coefficient of 24.7 $1/(K \times 10^{-6})$.

The alloy Castaduct-42, unlike classic AlSiMg alloys, has no hysteresis when heated up to 300 °C.

The lack of silicon content proves to be another advantage of Castaduct-42: There is no detectable dimensional change after heat input. A possible component distortion after exposure to heat is thus prevented in the best possible way.

**Application of Castaduct-42 in HPDC**

Generally, the Si-free die-casting alloy Castaduct-42 can be processed in established die-casting cells, with set up for the production of e.g. structural parts.
Due to its chemical composition, Castaduct-42 has noticeably lower latent heat and a somewhat higher coefficient of thermal expansion in comparison to conventional AlSi casting alloys and is thus closer to the values of magnesium die-casting alloys.

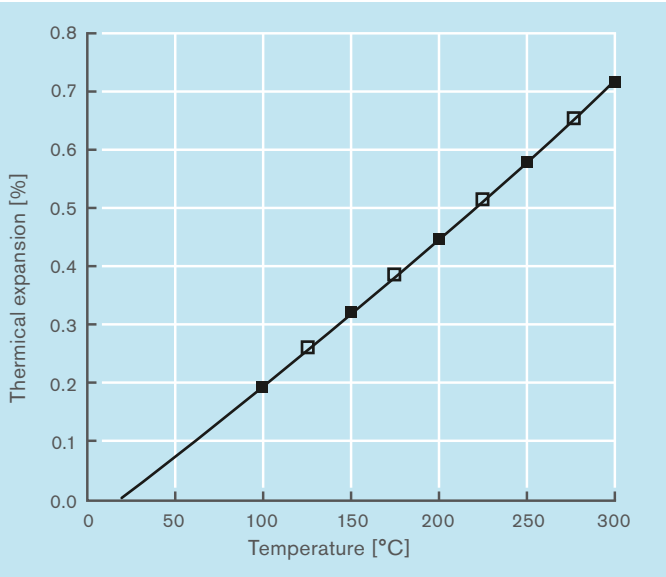



Fig. 8: Dilatometer curve of Castaduct-42, AlMg4Fe2 after two heatings

**Shrinkage behavior**

Also, the shrinkage behavior is comparable to magnesium die-casting alloys and thus more pronounced than with AlSi casting alloys. This has the consequence that the melt which is shot into the mold cavity discharges the latent heat in a shorter time to the die-casting mold contour, thus solidifying in a shorter time interval and due to the higher shrinkage factor from the liquid to the solid state of aggregation. Thus tends to jamming effects on the shape of die-casting mold inserts.
The tendency to jam on die-casting mold inserts is not to be confused or even equate set with the sticking tendency of a casting alloy with lower Fe contents and is controllable in the casting process with suitable measures in a simple manner.

The shrinkage behavior of Si-free or Si-poor AlMg die-casting alloys can lead to increased micro porosity, means formation of micro shrink holes due to shrinkage deficits, and also lead to sinkholes in the area of material amassing. Sink holes occur in particular where hot spots occur in a die-casting mold together with material amassing.
The shrinkage of Castaduct-42 casts is slightly larger than for AlSi alloys and is about 0.5 % to 0.9 %.

The solidification interval with 635 °C liquidus and 580 °C solidus temperature is on average 20 to 30 °C higher than with AlSi die-casting alloys.

**Design of casts**

For Castaduct-42 casts, therefore, the special properties of this innovative casting alloy must be considered both in the design of the casts and mold design and in the design of the mold HPDC process. More detailed information can be found in the chapter Design guidelines for casts and die-casting molds.

**Melt process**

The Castaduct-42 is an AlMg-type alloy with high Fe content and must not be contaminated with Si or Mn. A microstructural modification as required with AlSi structural casting alloys is not required. The tendency to oxidation on the surface of the melt bath is considerably reduced by a low content of oxidation-inhibiting alloying ingredients. Agglomerations of oxides on bath surfaces and on the bottom of the furnace barely form.

After rapid melting of the ingots a melt cleaning with a gas rotor have to be carried out. The properties of Castaduct-42 are retained if no sodium-containing treatment fluxes, no grain refining or modification, no phosphorus, alkali and earth alkali containing substances and no different metals are supplied to the melt. The temperature during melting should not permanently exceed 780 °C. The holding temperature after melting should be set to 760 °C (Fig. 9).

In melting furnaces, which keep the melt moving with heat convection, the form of lids are reduced by less oxide-melt reactions and segregations. This also applies to furnaces in which the bath movement takes place by means of rotor or purge gas initiation by furnace bottom stones.

Furnaces with roof heating and no bath movement cause difficulties for longer holding time without additional refilling due to the production with AlMg alloys.

Melting of all aluminum alloys and also Castaduct-42 reacts less with the refractory material, if it contains more than 85 % aluminum oxide.

The remelting of runners, return scrap and others is not a problem. However, care must be taken that mixing with other alloys cannot take place. In particular, an increase in the silicon content has a negative effect on the mechanical properties.

When using return material, a good melt cleaning by means of rotor and argon or nitrogen gas is absolutely necessary, since oxide inclusions, oxide skins, etc. have to be removed. These can accumulate in the melting and casting process and exert a negative influence on the component properties.

The resulting dross after cleaning and degassing cycle can be reduced in their metal content with use of sodium-free treatment flux.

**Casting process**

The quality of the cast, with regard to the mechanical characteristics, the ability to deform and the weldability, is primarily determined by the proportion of oxides and other impurities in the melt and by the gases entrapped in the casts.
These may be due to the $H_2$ content of the melt, residual air in the die-casting mold cavity, release agent residues, casting piston lubricants and residuals of moisture.
Already the melt handling in the foundry can have a big influence on the quality of the casts. A high melt temperature can lead to increased oxidation of the melt, which on the other hand leads to higher oxide and hydrogen levels.

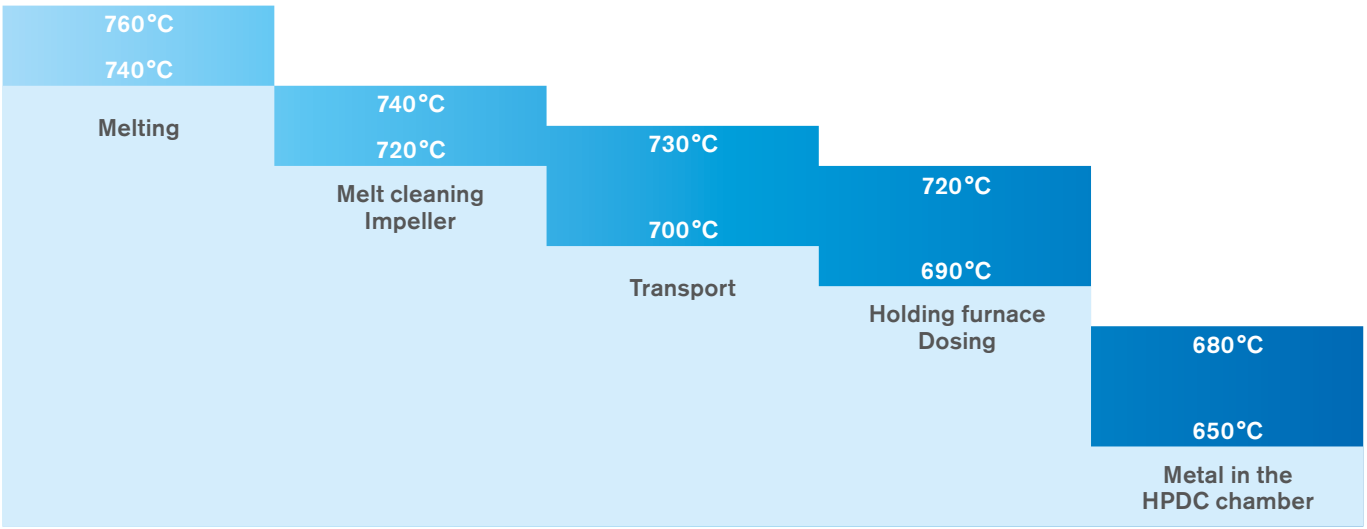



Fig 9: Typical temperature losses in melt handling during casting process; here with Castaduct-42, AlMg4Fe2

# Castaduct®-42 [AlMg4Fe2] – Properties

The dosage of the melt can be done by conventional dosing furnace or ladle furnace.
The Castaduct-42 casting alloy has a higher tendency to oxidize due to its higher Mg content and forms somewhat thicker oxide skins compared to AlSi casting alloys.

The carryover of oxide skins into the shot sleeve can be minimized if the dosing launder between dosing furnace and shot sleeve is made of a ceramic material and this is additionally heated.

A covered and heated dosing launder gives best performances. An optimum is the gassing of the closed and heated dosing tube with dry nitrogen or argon.

When using a ladle furnace, the dosing ladle must be ceramic and ideally can be preheated directly above the melt pool surface at high temperature. The oxide flags forming inside the ladle during the dosing process must be removed in a suitable manner before the renewed dosing process e.g. pour or blow out.

The dosing into the heated shot sleeve must take place as turbulent free as possible in order to avoid renewed oxide formations, combined with the increase in $H_2$ contents, optimally. I.e. low drop heights or not too steep dosing launder draft angles must be taken into account.

To minimize pre-solidification of the melt within the shot sleeve, it must be heated right through to temperatures of above 250 °C. Ideally, this is done by a temperature control with thermal oil or an electric heater.

It is recommended to maintain a filling ratio in the casting chamber of about 50 %. The lower the filling ratio, the greater the temperature drop of the melt in the shot sleeve and the greater the proportion of pre-solidification.
After dosing, the settling time of the melt within the shot sleeve should be kept as short as possible. Ideal are times less than 2 seconds.

Experience with the processing of Castaduct-42 showed that it is possible to go without the biscuit cooling in the front end of the shot sleeve, which is designed often as a water jacket. The cooling of the biscuit takes place sufficiently quickly via the casting piston cooling and the impact plate or the protrude anvil, both with integrated cooling, both located at the movable mold half. This promotes the minimization of pre-solidification within the shot sleeve which is important for best cast quality.

The die-casting mold inserts of the mold have to be preheated to temperatures of preferably above 180 °C, measured on the die-casting mold surface. With the steady casting process, a surface temperature of about 200 to 240 °C should be set, e.g. also be able for realization of long flow paths within the die-casting mold cavity.

For vacuum-supported structural casts, the use of double-sealed casting plungers, so-called vacuum casting plungers, is recommended. These ensure that when opening the vacuum valves less of secondary air is drawn through the melt by air gaps between the casting piston and the shot sleeve, which could take part of rapidly solidified melt surface, and laden with oxides, into the runner or even in the die-casting mold cavity.

If a water-based mold release agent is used, it is recommended that it should be applied with 30 % to 50 % more concentrated than is usual with AlSi casting alloys.
This serves to better demolding of Castaduct-42 from the die-casting mold contour, because Castaduct-42 tend to jamming. Mold release agents developed for the processing of AlMg alloys improve the flowability, the sliding on ejection and the weldability of the die-cast.

It is highly recommended to apply a release agent using a minimum-quantity spray process, i.e. water or oil based Microspray application. This will be avoid the use of large amounts of water, which would lead to a high temperature drop at the die-casting mold surface from casting cycle to casting cycle.
Furthermore, the visual quality of the cast surface and the quality of the cast in general significantly improves and the wear and tear of the die-casting mold inserts is positively influenced.

Due to the jamming tendency of Castaduct-42 during solidification in the die-casting mold cavity, based on the higher shrinkage factor in conjunction with the faster heat dissipation, the solidified cast must be demolded quickly from the die-casting mold inserts. The practice with Castaduct-42 shows that the shortening of the cycle times, in particular the significant shortening of the solidification time in the 3rd phase, leads to a better ejecting of the casts out of the die-casting mold. Thus, in general, the jamming tendency of AlMg die-casting alloys can be counteracted in a simple manner.
At the same time a possible deformation of the cast is counteracted during demolding.
By shortening the total cycle time, the temperature at the die-casting mold contour is maintained at the desired high level.

**HPDC start and die-casting cycle**

Due to the jamming tendency also the initial casts must be completely poured on the die-casting machine.
Casting at too low shot speed will not ensure the integrity of the cast and a safely demold of the cast is not possible. The ejector pins may pierce through the unfinished cast.
It is recommended to pour the initial casts with at least 70 % of the plunger speed selected for the series process. Furthermore, it is necessary to avoid any termination of the started 2nd phase in the course of the HPDC cycle.

As part of testing the Castaduct-42 in existing AlSi die-casting molds, the solidification times could be reduced down to the single-digit seconds range!
The total cycle times in the die-casting process could be reduced by one- or two-digit seconds using the Castaduct-42 die-casting alloy!

**Trimming process**

The Castaduct-42 casts can be cooled directly from the casting heat in a water bath or in air. The type of cooling has no noticeable influence on the material properties of the finished cast.

For ductile die-casting alloys it is recommended to use a cutting blade designed with a sloping surface, so that the ingate section, runners, burrs, overflows and venting channels are cut off with less force. Flat-faced punching blades squeeze with greater effort from the ingate section, with the risk of break-outs may exist. When using cutting blades that are sloped with an angle of approx. 3° to 5°, the required stroke for the deburring cut only increases minimally.

The trials in the context of alloy development showed that after demolding the cast from the die-casting mold, the shrinkage of the solid is only slightly greater than with casts made of AlSi casting alloys: The casts made with Castaduct-42 were punched on a trimming tool without damage, even if designed for trimming of AlSi casts.

**Case Study**

The sample cast was a structural casting with 910 mm length, 510 mm width and 6.5 kg part weight, with Castaduct-42 alloy in a die-casting cell designed for AlSi10MnMg applications. The shot weight was about 11 kg.
The wall thickness was over the flow path length of 850 mm in the region of the ingate 3.5 mm and in the back wall 2.5 mm.

The Castaduct-42 was stored and kept warm in a conventional, closed dosing furnace at 710 °C, later in the course of the trial at 690 °C.

The temperature level of the die-casting mold was raised to above 200 °C. As a result, the die-casting mold temperature was on average 50 °C higher than that with AlSi alloys.
Significant is the reduction of the solidification time until ejection in the context of the trial of originally 16 seconds to 10 seconds. The biscuit cooling at the front end of the casting chamber was switched off.

The plunger speed for the die-casting shot was set for a cavity filling time of 49 ms, which made possible by the higher die-casting mold temperature.

For the startup of the HPDC trial the release agent to water ratio was increased for a more rich mixture from 1:100 for AlSi alloys to 1:50 for AlMg alloys.
All Castaduct-42 casts were trimmed hand-hot without problems with the standard trimming tool by use of the automatic sequence in the die-casting cell.

A total of about 175 shots were poured, of which 130 shots continuously without any interruptions. Overall, the casting result was classified as very good. The mold filling capacity is pleasingly good. The casts could be poured cleanly without signs of cold flow, hot cracks or pulling marks. The die-casting mold itself showed no adhesions or soldering in the area of the hollow cavity, which would have led to pulling marks.

The measured mechanical properties for yield strength ($R_{p0.2}$), tensile strength ($R_m$) and elongation (E) from Castaduct-42 structural in as-cast condition were better at yield strength and elongation when compared to alloy AlSi10MnMg plus annealing treatment to the state O.

| | $R_{p0.2}$ (YTS) [MPa] | $R_m$ (UTS) [MPa] | A (E) [%] |
|---|---|---|---|
| Structural cast | 120 – 137 | 241 – 268 | 7.5 – 17.6 |
| average | 129 | 250 | 11.4 |

Mechanical properties of HPDC trials with Castaduct-42, AlMg4Fe2

In critical cast areas with strongly turbulent filling, individual lower values for the elongation at break were measured analogously to the alloy AlSi10MnMg at annealing state O.

# Profile of the alloys for the die-casters

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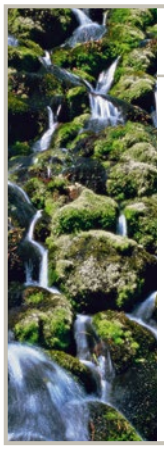
## Get the spirit of RHEINFELDEN



### Silafont®-38 [AlSi9MnMgZn]

- **applicable to thinnest wall designs and complex designs**
- **air quenching after solutionizing reduce distortion of the casts**
- **alloying elements enables highest strength and good crash properties**
- good corrosion resistance due to exact alloy limits
- high fatigue properties
- excellent weldability and machinability
- suitable for self-piercing

| Treatment state | YTS [MPa] | UTS [MPa] | E [%] | Hardness [HBW] |
|---|---|---|---|---|
| water-T6 | 230–280 | 300–350 | 6–9 | 90–115 |
| air-T6 | 180–210 | 250–280 | 8–11 | 80–110 |

### Castasil®-37 [AlSi9MnMoZr]

- **no heat treatment needed to reach high elongation**
- **good die-cast ejectability**
- **usable even for thinnest wall thicknesses**
- long-term stability
- high yield strength and excellent elongation in the as-cast state due to defined alloying elements
- very good corrosion resistance
- **high fatigue stress resistance;** highest compaired to AlSi-alloys
- excellent weldability
- suitable for self-piercing riveting

| Treatment state | Wall thickness [mm] | YTS [MPa] | UTS [MPa] | E [%] |
|---|---|---|---|---|
| F | 2–3 | 120–150 | 260–300 | 10–14 |
| F | 3–5 | 100–130 | 230–280 | 10–14 |

### Castasil®-21 [AlSi9SrE]

- **highest thermal and electrical conductivity** compared to AlSi die-casting alloys due to low disturbing impurities
- thin wall design possible
- **good die-cast ejectability**
- long-term stability after temper O
- **high yield strength and elongation in the as-cast state or after temper O, compared to Al for rotors**
- suitable to flanging, clinching or self-piercing, especially in temper O

| Treatment state | YTS [MPa] | UTS [MPa] | E [%] | Conductivity [IACS%] |
|---|---|---|---|---|
| F | 85–100 | 200–230 | 6–9 | < 43.5 |
| O | 80–100 | 170–200 | 9–15 | < 48.5 |

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## Magsimal®-59 [AlMg5Si2Mn]

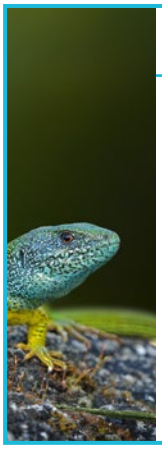
- **usage in the as-cast state for HPDC with 2 to 8 mm wall thickness**
- **low melt oxidation due to patented alloy addition**
- **high-tech alloy**
- low sticking to the mold
- higher shrinkage in comparison to AlSi-alloys
- **excellent corrosion resistance**
- **very high fatigue strength**
- excellent weldability, suitable for flanging, clinching and self-piercing riveting

| Treatment state | Wall thickness [mm] | YTS [MPa] | UTS [MPa] | E [%] |
|---|---|---|---|---|
| F | 2–4 | 160–220 | 310–340 | 11–22 |
| F | 4–6 | 140–170 | 250–320 | 9–14 |

## Magsimal®-plus [AlMg6Si2MnZr]

- **best in class YTS and still 8 % E in as-cast state for HPDC with 2 to 6 mm wall thickness**
- **low melt oxidation due to patented alloy addition**
- **high-tech alloy**
- **different alloying elements to control**
- low sticking to the mold
- higher shrinkage in comparison to AlSi-alloys
- **excellent corrosion resistance**
- excellent weldability, suitable for flanging, clinching and self-piercing riveting

| Treatment state | Wall thickness [mm] | YTS [MPa] | UTS [MPa] | E [%] |
|---|---|---|---|---|
| F | 2–3 | 200–220 | 340–360 | 9–12 |
| T5 | 2–3 | 230–250 | 350–380 | 8–12 |



## Castaduct®-42 [AlMg4Fe2]

- **usage in the as-cast state especially for large and thin wall HPDC**
- **low melt oxidation due to special alloy addition**
- **smart alloy composition with an AlFe eutectic**
- **easy handling**
- **no sticking to the mold due to high Fe content**
- **higher shrinkage due Si is < 0.20 %**
- highest elongation even at room temperature
- **excellent corrosion resistance**
- long therm stability

| Treatment state | Wall thickness [mm] | YTS [MPa] | UTS [MPa] | E [%] |
|---|---|---|---|---|
| F | 2–4 | 120–150 | 240–280 | 10–22 |

# Technical informations

This chapter is provided on how to work with our casting alloys in the melt process and how to gain optimum pouring results. In the various steps in the die-cast process as possible grain refinement, strontium modification, quality of melt, heat treatment for HPDC, surface coating, and joining techniques for the HPDC is hereby received.

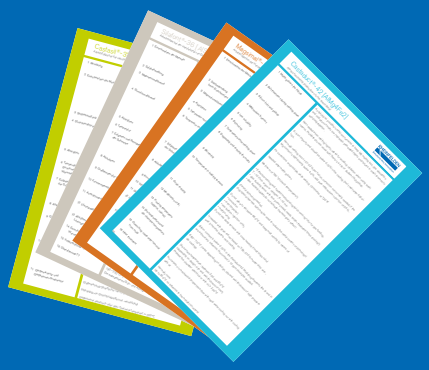
> We consider this a very important part of the manual as it isn't just the quality of casting alloy used which is key to successful applications, the right way of working before, during and after pouring is also of great importance. More questions will certainly arise during your work and as new developments enter the market.
> The RHEINFELDEN ALLOYS foundry specialists will happily answer these.

The mechanical properties are based on in-house measurements of our alloys and if applicable most exceed the values stipulated in the EN 1706 European standard.

The mechanical values were measured at tensile bars, machined from HPDC. The ranges of mechanical properties stated indicate the performance of the alloys and the amount of scatter depending on material and pouring. The respective maximum value is for the designer's information. These values can also be reached in the cast or sub-areas with favorable casting conditions and corresponding casting technology work.

The HPDC alloys supplied by RHEINFELDEN ALLOYS have small and precisely defined analysis ranges in order to ensure good uniformity in the casting process and other properties.

# Processing datasheets



RHEINFELDEN ALLOYS provides the following processing data sheets in order to detail how to work with the various alloys. If you use our casting alloys, please feel free to copy the following pages and use them in your company. They contain practical instructions and demonstrate the processes step by step.

Not all alloys are listed here, but the processing data sheet from within the corresponding alloy family can be used. The recommendations correspond to typical foundry circumstances. For example a crucible or tower melting furnace is considered for melting down; the circumstances in a huge melting furnace may differ from the recommendations. Fine returns should also not be used for primary aluminum HPDC alloys.

The volumes listed here are all percentages by weight, calculated for the charge weight. The temperatures quoted all relate to the temperature of melt, even for casting. The heat treatment recommendations apply for the standard process and may be varied, to minimise distortion for example.

If you have any questions relating to your specific alloy application and processing, please contact our foundry experts.

# Silafont®-38 [AlSi9MnMgZn]

Sequence of work when producing high pressure die-casts from Silafont-38

| | |
|---|---|
| 1 Melting down the ingots | As quickly as possible in efficient furnaces to keep magnesium melting loss, gas absorption and oxidation of melts low; replenish preheated ingots and returns in small volumes to avoid segregation and entrapped oxides; proportion of returns may extend to 50 % |
| 2 Flux treatment | Not needed when melting |
| 3 Magnesium burnout | Normally a melting loss of 0.03 % per fusion; compensation is only required if the magnesium content of the melts is outside tolerance, add magnesium master alloy or pure magnesium |
| 4 Strontium burnout | Usually melting loss of 30 – 50 ppm per fusion; Sr should only be added if the Sr content of the melts is less than 80 ppm, add AlSr5 or AlSr10.<br>When fusing for the first time in a new crucible or in a crucible which has not yet been used for Sr-modified alloys, the Sr content falls sharply. Strontium will diffuse into the crucible, saturation is reached after the first fusion |
| 5 Skimming | Needed after melting down |
| 6 Temperature | After melting down maximum of 780 °C for holding temperature |
| 7 Degassing and refining the melts | • In the transport crucible, better in a holding crucible or receptacle or in a dosing furnace with bottom blocks; effective refining and fastest method using quick-running rotor for gas feeding, 7 – 10 l/min argon or nitrogen, 6 – 10 min<br>• Gas flushing lance with fine porous head, needs longer treatment times (cooling!)<br>• Gas flushing tablets emitting nitrogen in the bell plunger procedure are not very suitable |
| 8 Skimming | Required after melting down; the metal content of the skimmings may be reduced by adding melt fluxes within or after the impeller treatment |
| 9 Pouring temperature (approx. values) | 680 – 710 °C – depends on design, flow path and wall thickness of high pressure die-cast, but also on the length of the flow channel in the dosing furnace and possibly on chamber heating |
| 10 Mold temperature | Mold surface temperature 250 – 350 °C |
| 11 Solution heat treatment | 470 – 490 °C / 2 – 3 hours; for special components: 420 °C / 0.5 hours |
| 12 Cooling with air | Immediate air cooling with a cooling rate of > 3 °C/s is only achieved with an intensive air stream (down to 200 °C) and results in lower distortion. If cooling in the air, only a significantly lower yield tensile strength can be obtained |
| 13 Cooling with water | In water (10 – 60 °C) without a delay wherever possible |
| 14 Delay time before artificial ageing | Only if straightening is needed, usually maximum of 12 hours |
| 15 Full artificial ageing T6-water | 155 – 190 °C / 1 – 3 hours |
| 16 Full artificial ageing T6-air | 155 – 210 °C / 1 – 3 hours |
| | The annealing and ageing times stated apply without a heating-up time |

# Castasil®-37 [AlSi9MnMoZr]

Sequence of work when producing high pressure die-casts from Castasil-37

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| | |
|---|---|
| 1 Refining | Clean furnace, crucible, treatment and casting tools to avoid impurities from unwanted elements such as Cu, Zn and especially Mg! |
| 2 Melting down the ingots | The melt should be quickly heated to above 670 °C to avoid segregations, e.g. of the solid solution containing Mn in the melt. The temperature of melt should not exceed 780 °C. An Sr melting loss should be expected when melting and keeping warm – the higher the temperature, the greater the loss. Sr melting loss should be expected in particular when melting down returns and degassing treatment is recommended to remove the $H_2$ and oxides. As the Sr content increases, so does the tendency for the melt to absorb hydrogen; this should not therefore exceed 350 ppm. |
| 3 Flux treatment | Not needed when melting |
| 4 Strontium burnout | Usually melting loss of 30 – 50 ppm per fusion; Sr should only be added if the Sr content of the melts is less than 60 ppm, add AlSr5 or AlSr10.<br>When fusing for the first time in a new crucible or in a crucible which has not yet been used for Sr-modified alloys, the Sr content falls sharply. Strontium will diffuse into the crucible; saturation is reached after the first fusion |
| 5 Skimming | Needed after melting down; as well as their potential for danger, cold tools may result in molybdenum segregation |
| 6 Temperature after melting down | After melting down maximum of 780 °C for holding temperature. Don't keep the melt at temperature below 680 °C and steer melt if possible |
| 7 Degassing and refining the melts | • In the transport crucible, better in casting or dosing furnace; effective refining and fastest method using quick-running rotor for gas feeding, 7 – 10 l/min argon or nitrogen, 6 – 10 min; during degassing in the transport crucible, cooling of 30 – 50 °C should be expected<br>• Gas flushing lance with fine porous head, needs longer treatment times (cooling!)<br>• Tablets for melt cleaning are inefficient |
| 8 Skimming | Required after degassing; the metal content of the skimmings may be reduced by adding melt fluxes during or after impeller treatment |
| 9 Pouring temperature (approx. values) | 680 – 720 °C depends on design, flow path and wall thickness of high pressure die-cast, but also on the length and insulation of the flow channel from the dosing furnace and on use of shot sleeve heating.<br>Temperature losses may cause initial solidification and should therefore be avoided |
| 10 Mold temperature | 250 – 350 °C, depending on cast and requirements of mechanical properties<br>As a rule: the warmer the mold, the higher the elongation and the lower the strength. |
| 11 Casting chamber temperature | Preheat the chamber electrical or with oil > 200 °C |

# Castasil®-21 [AlSi9SrE]

Sequence of work when producing high pressure die-casts from Castasil-21

RHEINFELDEN
Solutions thru Innovation

| | |
|---|---|
| 1 Refining | Clean furnace, crucible, treatment and casting tools to avoid impurities from unwanted elements such as Cu, Mg, V, Cr and especially Mn an Ti! |
| 2 Melting down the ingots | The melt should be quickly heated to above 670 °C to avoid segregations, e.g. of the solid solution containing Mn in the melt. The temperature of melt should not exceed 780 °C. An Sr melting loss should be expected when melting and keeping warm – the higher the temperature, the greater the loss. Sr melting loss should be expected in particular when melting down returns and degassing treatment is recommended to remove the $H_2$ and oxides. As the Sr content increases, so does the tendency for the melt to absorb hydrogen; this should not therefore exceed 350 ppm. |
| 3 Flux treatment | Not needed when melting |
| 4 Strontium burnout | Usually melting loss of 30 – 50 ppm per fusion; Sr should only be added if the Sr content of the melts is less than 100 ppm, add AlSr5 or AlSr10.<br>When fusing for the first time in a new crucible or in a crucible which has not yet been used for Sr-modified alloys, the Sr content falls sharply. Strontium will diffuse into the crucible; saturation is reached after the first fusion |
| 5 Skimming | Needed after melting down |
| 6 Temperature after melting down | After melting down maximum of 780 °C for holding temperature. Don't keep the melt at temperature below 680 °C and steer melt if possible |
| 7 Degassing and refining the melts | • In the transport crucible, better in casting or dosing furnace; effective refining and fastest method using quick-running rotor for gas feeding, 7 – 10 l/min argon or nitrogen, 6 – 10 min; during degassing in the transport crucible, cooling of 30 – 50 °C should be expected<br>• Gas flushing lance with fine porous head, needs longer treatment times (cooling!)<br>• Tablets for melt cleaning are less efficient |
| 8 Skimming | Required after degassing; the metal content of the skimmings may be reduced by adding melt fluxes during or after impeller treatment |
| 9 Pouring temperature (approx. values) | 680 – 720 °C depends on design, flow path and wall thickness of high pressure die-cast, but also on the length and insulation of the flow channel from the dosing furnace and on use of shot sleeve heating.<br>Temperature losses may cause initial solidification and should therefore be avoided |
| 10 Mold and chamber temperature | 250 – 350 °C, depending on cast and requirements of mechanical properties<br>As a rule: the warmer the mold, the thinner the fins may be designed.<br>Preheat the chamber electrical or with oil > 200 °C |
| 11 Annealing to high conductivity in temper O | 250 – 350 °C for 2 – 3 hours; for special purpose 440 °C for 6 hours<br><br>The annealing and ageing times stated apply without a heating-up time |

# Magsimal®-59 [AlMg5Si2Mn]

Sequence of work when producing high pressure die-casts from Magsimal-59

RHEINFELDEN
Solutions thru Innovation

| | |
|---|---|
| 1 Melting down the ingots | As quickly as possible in efficient furnaces to keep Mg melting loss, gas absorption and oxidation of melts low; replenish preheated ingots and returns in small volumes to avoid segregation; use refractory materials with a high clay content; avoid phosphorous and sodium absorption |
| 2 Flux treatment | Prohibited to use usual flux! There is a risk of sodium (Na) pick up |
| 3 Magnesium burnout | Normally melting loss of 0.1 % per fusion, correction not normally needed; if the Mg content is significantly below 5.0 %, add pure magnesium of maximum 0.5 % |
| 4 Skimming | Needed after melting down |
| 5 Temperature after melting down | Maximum of 780 °C (check temperature!) |
| 6 Temperature in holding furnace | Holding furnance temerature: 700 – 720 °C<br>Do not allow to fall below 650 °C and keep melt moving by means of:<br>• convection<br>• rotor (impeller)<br>• use bottom injection of $N_2$<br>• melt pouring<br>Do not use deep furnace with cover heating if melt is calm! |
| 7 Degassing and refining the melts | • Effective refining and fastest method using quick-running rotor for gas feeding, 7 – 10 l/min argon or nitrogen, 6 – 10 min<br>• Gas flushing lance with fine porous head, needs longer treatment times (cooling!)<br>• Gas flushing tablets do not achieve the necessary effect! |
| 8 Skimming | Careful skimming needed!<br>Only totally Na-free fluxes may be used to reduce the metal content of skimmings! |
| 9 Grain refining | Prohibited! |
| 10 Modification | Prohibited! The elongation achievable would be reduced considerably |
| 11 Pouring temperature (approx. values) | 690 – 730 °C, varies depending on design, size and wall thickness of high pressure die-casts |
| 12 Mold temperature and casting chamber temperature | Mold surface temperature 250 °C to 350 °C, depending on cast and requirements of mechanical properties<br>As a rule: the warmer the mold, the higher the elongation and the lower the strength.<br>Preheat the chamber electrical or with oil > 200 °C |
| 13 Quenching casts after removal from mold | Immediate quenching in water reduces the yield tensile strength and increases elongation |
| 14 Heat treatment | Normally none |
| 15 stress-relief annealing | Only in special cases for T5 and O; if necessary, age T5 at up to 250 °C and for up to 90 min, the yield tensile strength will increase and elongation decrease; if necessary, age O at between 320 °C and 380 °C and for up to 90 min, the yield tensile strength will decrease and elongation increase |

# Magsimal®-plus [AlMg6Si2MnZr]

Sequence of work when producing high pressure die-casts from Magsimal-plus

RHEINFELDEN
Solutions thru Innovation

| | |
|---|---|
| 1 Melting down the ingots | As quickly as possible in efficient furnaces to keep Mg melting loss, gas absorption and oxidation of melts low; replenish preheated ingots and returns in small volumes to avoid segregation |
| 2 Flux treatment | Prohibited to use usual flux! There is a risk of sodium (Na) pick up |
| 3 Magnesium burnout | Normally melting loss of 0.1–0.2 % per fusion, correction not normally needed; if the Mg content is significantly below 6.0 %, add pure magnesium of maximum 0.5 % |
| 4 Skimming | Needed after melting down |
| 5 Temperature after melting down | Maximum of 780 °C (check temperature!)<br>Holding furnance temerature: 700 – 720 °C |
| 6 Temperature in holding furnace | Do not allow to fall below 650 °C and keep melt moving by means of:<br>• convection<br>• rotor (impeller)<br>• use bottom injection of Nitrogen-gas ($N_2$)<br>• melt pouring<br>Do not use deep furnace with cover heating, if melt stays calm! |
| 7 Degassing and refining the melts | • Effective refining and fastest method using quick-running rotor for gas feeding, 7 – 10 l/min argon or nitrogen, 6 – 10 min<br>• Gas flushing lance with fine porous head, needs longer treatment times (cooling!)<br>• Gas flushing tablets do not achieve the necessary effect! |
| 8 Skimming | Careful skimming needed!<br>Only totally Na-free fluxes may be used to reduce the metal content |
| 9 Grain refining | Prohibited! |
| 10 Modification with Na or Sr | Prohibited! The elongation achievable would be reduced considerably |
| 11 Pouring temperature (approx. values) | 690 – 730 °C, varies depending on design, size and wall thickness of HPDC<br>Mold surface temperature 250 °C to 350 °C, depending on cast design and requirements of mechanical properties |
| 12 Mold temperature and casting chamber temperature | As a rule: the warmer the mold, the higher the elongation and the lower the strength. Preheat the chamber electrical or with oil > 200 °C |
| 13 Quenching casts after removal from mold | Immediate quenching in water reduces the yield tensile strength and increases elongation. Stabile mechanical propeties are achieved after 20 days |
| 14 Heat treatment with solutionising | Normally none |
| 15 Rapid annealing with T5 | If necessary, age T5 at 170 °C up to 250 °C and for 30 up to 90 min, the yield tensile strength will increase and elongation decrease slightly |
| 16 Stress-relief annealing like temper O | If necessary, age at temperature between 320 – 380 °C and for up to 90 min, the yield tensile strength will decrease and elongation increase |

# Castaduct®-42 [AlMg4Fe2]

Sequence of work when producing high pressure die-casts from Castaduct-42

RHEINFELDEN
Solutions thru Innovation

| | |
|---|---|
| 1 Melting down the ingots | As quickly as possible in efficient furnaces to keep Mg melting loss, gas absorption and oxidation of melts low; replenish preheated ingots and returns in small volumes to avoid segregation. |
| 2 Flux treatment during melting down | Not needed when melting ingots; useful for avoiding oxidation when using small returns. Prohibited to use usual flux! There is a risk of sodium (Na) pickup. |
| 3 Silicon limit and pickup | Si is an impurity and should be below 0.2% in the cast. Don't melt after AlSi alloys. |
| 4 Magnesium burnout | Normally melting loss of 0.1–0.2% per fusion, correction normally not needed; if the Mg content is significantly below 4.0%, add pure magnesium in portion of 0.4%. |
| 5 Iron content | Normally no correction of Fe is needed |
| 6 Skimming | Needed after melting down |
| 7 Temperature after melting down | Maximum of 760°C (check temperature!) |
| 8 Degassing and refining the melts | • Effective refining and fastest method using quick-running rotor for gas feeding, 7–10 l/min argon or nitrogen, 6–10 min<br>• Gas flushing lance with fine porous head, needs longer treatment times (cooling!)<br>• Gas flushing tablets do not achieve the necessary effect! |
| 9 Skimming | Careful skimming needed!<br>Only special Na-free fluxes may be used to reduce the metal content of skimmings! |
| 10 Temperature in holding furnace | Do not allow to fall below 660°C and keep melt moving by means of:<br>• convection<br>• rotor (impeller)<br>• use bottom injection of $N_2$<br>• melt pouring<br>Do not use deep furnace with cover heating if melt stays calm! |
| 11 Grain refining | Not needed for thin-walled die-casts |
| 12 Modification of Si | Silicon content is below 0.15% in the Castaduct-42. Modifying elements like Sr and P are without any influence. Na content >10 ppm should be avoided. |
| 13 Pouring temperature (approx. values) | 680–710°C, varies depending on design, size and wall thickness of high pressure die-casts |
| 14 Mold temperature and casting chamber temperature | Mold surface temperature: between 200 and 350°C<br>(depending on design, size and wall thickness of cast)<br>Preheat the chamber electrical or with oil > 200°C |
| 15 Quenching casts after removal from mold | No variation in mechanical properties either with rapid water cooling nor with cooling with air |
| 16 Heat treatment | Normally none<br>Up to 350°C no influence to the metallic structure! |

**Design of structural die-casts**

Die-casted structural components are typically large stability-giving components, in which high component reliability is required and which should withstand high deformations in the event of crash of vehicles. This structural casts has to meet demands for high strength and elongation with fewest errors as possible in the cast structure. A structural cast is connected in individual areas with other components by welding, gluing, riveting or crimping.

The material-side fulfillment of high strength requirements, as possible without heat treatment to be applied, improves the dimensional accuracy of structural casts. The additional demand for lightweight construction is also met by thin-walled design and high functional integration.

Important for the production of structural casts is a castable component design with reliable processing technology of the HPDC alloys presented in this manual. Some hints for the design of the casts as well as the die-casting molds are given here. We recommend that you follow these design suggestions, especially when using our Magsimal-59 / -plus and Castaduct-42 alloys.

On the machine side, thin-walled structural casts with wall thicknesses of around 2.0 mm can be realized with flow path length of approximately 1.0 m. However, it is important to ensure that the wall thickness from casting ingate section to the end of mold filling is performed from thick to thin, so for example from 3.5 mm to 2.0 mm.

In the case of the more strong shrinking AlMg casting alloys, the draft angles should be performed on contours and cores preferably minimum 1.5°. Cast contours that tend to shrink more strong, as well as deep, slender fin contours must be supported with sufficient amount of ejectors for demolding from the die-casting mold. Examples are expressed in Fig. 1.

The diameter of the ejector pins should not be less than 6.0 mm, since AlMg casting alloys are expected to have significantly higher demolding forces compared to AlSi casting alloys. Also, the risk of buckling of the ejector pins can be avoided in a practicable way. In practice, the demolding forces are about one-third higher and may be even higher depending on the cast design. Additional ejector pins also significantly reduce the surface pressure on the hot cast and with this the possible distortion of the cast.

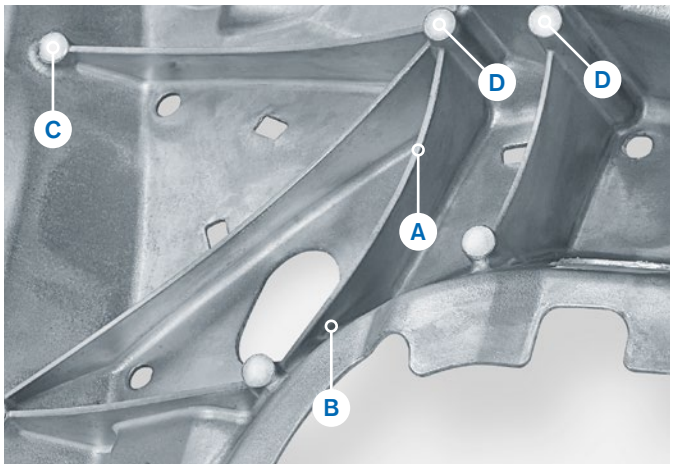


Fig. 1: An example of good fin design

A: Thin fin with lowered height in the middle of the length, also to reduce thickness at the fin ground

B: Adjusted core depth in small core areas

C: Ejector pin location in a tilted wall

D: Additional core pins in the area of narrow high fins

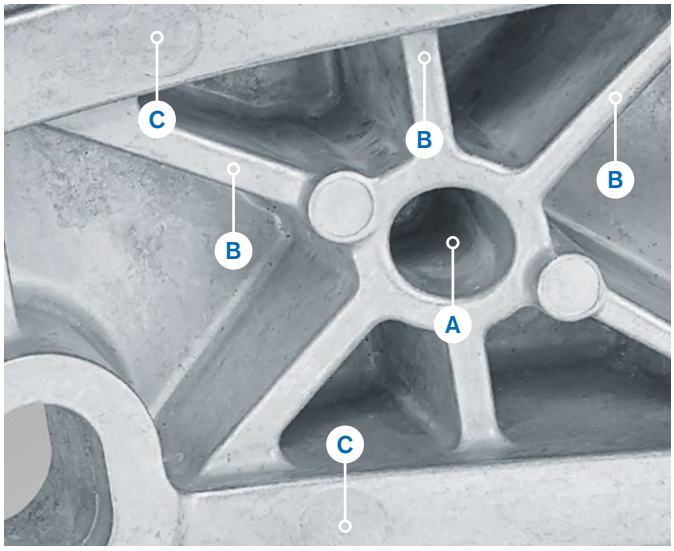


Fig. 2: An example of good fin design

A: Fin node reducing massive concentration

B: High incoming forces are spreaded by several fins

C: Thicker diameter of ejector pins to reduce pressure force

The demolding of long cores should preferably be done via sleeve ejectors. Where this cannot be done, hydraulically operated underfloor core pullers can be a viable solution.

When designing fins in a cast, nodes with undesirable accumulations of material should be avoided wherever possible.
In particular, high fins with large amount of taper at the flanks cause significant volume in the bottom of the fins. The volume contraction in such accumulations of material then causes externally visible sink marks at the floor bottom. Remedy can be here design provided beadings on the floor bottom side.

Deformations or even demolitions of large, core-shrinking accumulations of material, such as assembly domes in the regions of thin-walled cast contours, must be avoided. Important for such assembly domes is a generous connection to the thin-walled cast contours with the help of larger fin structures (Fig. 3).

Advantageous for large-area fin designs with good component rigidity and improved NVH characteristics are honeycomb-like fin structures. As a result, unfavorably designed and narrow tapered die-casting mold contours are avoided for the steel mold in a simple manner. The honeycomb structure with its hexagon design typically leads to 120° angles in the steel mold and thus reduces hot spots with the risk of hot work steel tempering temperatures above 550 °C during cavity filling (Fig. 4).

Small radii or even sharp edges should be avoided in die-cast design, especially when using AlMg casting alloys. Design specifications similar to Mg die-cast should be used. Small radii lead to hot cracks during solidification of the metal in the die-casting mold cavity, if there are long, freely shrinking solidification paths is present next to it.

Heat sinks and hot cracks in the area of inner radii can be defused by small additional fins. The skin layer formation is then improved by the larger contact surface with the hot-working steel (Fig. 5–7).

Other good examples of casting-oriented design are the BDG/VDG guideline K200 as well as the BDG/VDG guideline for die-cast made of non-ferrous metals.

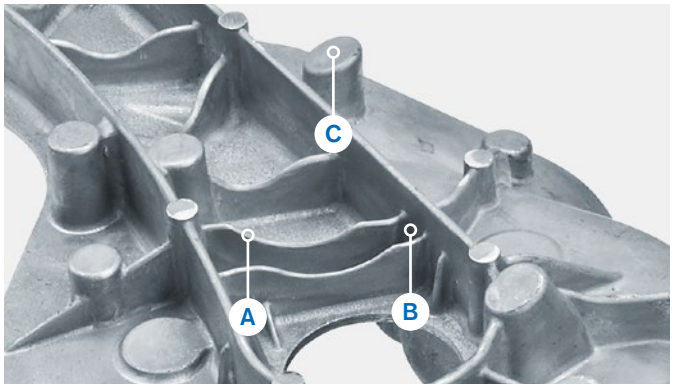


Fig. 3: An example of good fin design

A: Design of an U-profile with thin fins, lowered in height tofollow the real stress curve in case of load (FEM calculations)

B: Separated conjunction of fins to the outer wall to avoid thicker areas

C: Hollow design on the back-side of assembly domes

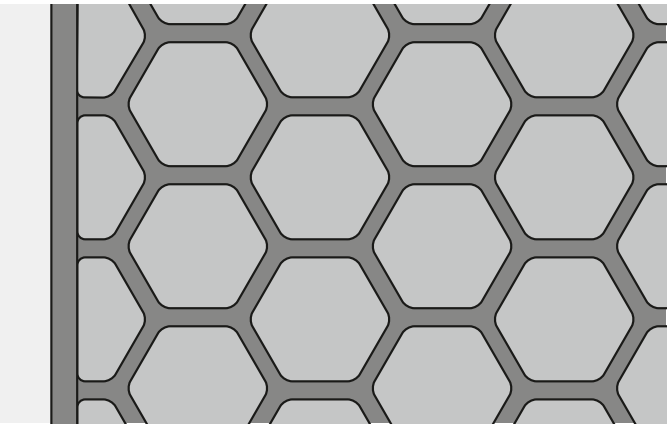

Fig. 4: An example of good fin design:
Honeycomb structure reduce hot spots on the mold steel

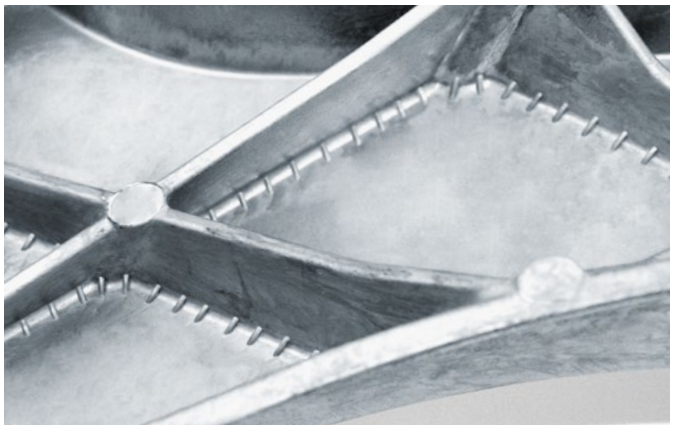

Fig. 5: Solidification support through riffles; an example of solving inner edge problems through small marks

**Design of the die-casting mold**

For the production of large and thin-walled structural die-casts, not only the casting alloy used, but also the die-casting mold itself has to be designed to reproduce long flow paths.

Ideal for thin-walled die-casts with Castaduct-42, Magsimal-59 or Magsimal-plus is the close-to-contour design of the cooling and tempering inside the mold inserts. For the die-casting process, a temperature control of the mold inserts to over 200 °C is recommended.

An adjustment of the thermal balance of the die-casting mold by spraying the die-casting mold contour with the help of water in combination with release agents should be avoided as far as possible. This is because stress cracks on the steel occur early when the temperature difference is particularly high. It is recommended to carry out the release agent application using a minimum-quantity spraying process. In this case, water, powder or oil-based release agents can be used. Modern simulation programs are of great help in the design of the thermal balance of a die-casting mold.

An intensive cooling of the mold inserts in the area of the cast runner allows rapid removal of the cast from the die-casting mold. Although a flat and wide developed cast runner increases the pressure surface within the die-casting mold and thus the necessary locking force, but it leads to significantly reduced solidification times. Thus, the casts can be demold in a faster way. Furthermore, large, flat cast runners can be divided more easily with less effort during the deburring cut. An advantage when it comes to the handling of return scraps.

The runner as well as the ingate section has to be designed for low turbulence and fluid flow favorable run, so without small radii and without sharp-edged transitions. Because these increase the flow resistance significantly and it is a greater casting force needed for the cavity filling. Cavitation effects lead to local vacuum zones with cross-sectional constrictions in flow-cross sections and can suck in air via the die-casting mold parting lines and with this into the melt.

The runner ingate section has to be placed into areas of the cast, where the incoming melt do not immediately encounters a transverse and rise barrier inside of the cavity within the flow direction. This leads, regardless of the casting alloy used, to very strong friction of the melt on the die-casting mold contour, so very quickly to local heat up, and as a result, to sticking and strong erosion. Even a significant loss of flow energy is expected.


Fig. 6: HPDC design to ensure forced solidification in the cast

A: Thinnered wall with small waffle pattern design to enlarge contact area

B: Separated fin connections

C: Outer contour casted with core to cast a wall with uniform thickness

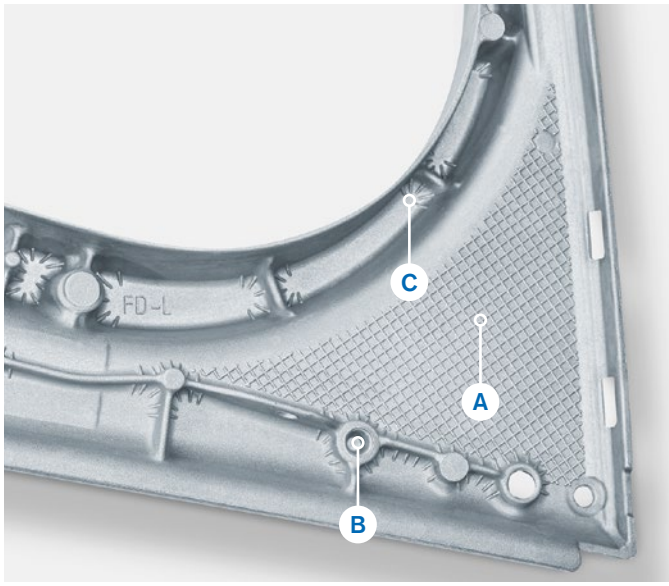


Fig. 7: Good HPDC design to ensure forced solidification in the cast

A: Thin wall with narrow small waffle pattern design to enlarge intensively the contact surface

B: Assembly domes with hollow casted center

C: Solving inner edge problems through small marks

The ingate cross-section has to be generously dimensioned so that the ingate speed of the melt remains between about 30 to 60 m/s and nevertheless a short cavity filling time is achieved. A short cavity filling time is necessary to reduce casting defects in thin-walled structural die-casts.
For the significant improvement of the flow properties in a die-casting mold cavity with Castaduct-42 or Magsimal-59 / Magsimal-plus alloys a slightly roughened surface structure on the die-casting mold contour is suitable. For this purpose, the local application of tungsten carbide layers as well as for large-scale application eroded, blasted or etched surfaces are suitable.

Also, waffle patterns are useful for improving flow properties in thin walled areas of casts, whereby the wall thickness between the small fins may decrease down to 1.2 mm (Fig. 6 and 7).

The die-casting mold for structural casts must be designed for a vacuum-assisted casting process. In this case, the correctly sized venting cross section is of great importance. It determines the achievable flow path length of the liquid metal within the cavity and the residual porosity in the cast (Fig. 8).

An as closed as possible melt front with only few dividing and re-joining melt front areas leads to less oxide formation during cavity filling and thus experience shows to significantly better casting results, than a chaotic and highly turbulent filled cavity. Converging and thus oxide-affected melt fronts must be able to run into overflows and ventilation channels in a defined manner.

Far-off ingate lying material accumulations, which cannot be feed via the thin-walled structures of the cast during solidification, must preferably be rapidly cooled. This can also be realized with highly dissipating die-casting mold contours made of wear-resistant tungsten steel parts inserts. Also specially designed core pins with internal cooling channels lead to a good heat dissipation.

Parts of die-casting mold inserts with almost any designed interior cooling can also be produced using the 3D forming process SLM. Here, however, the recommendation is to dimension the cooling channel cross-sections sufficiently large so that they do not block in the casting operation by deposits.

Nevertheless, upcoming shrinkage deficits in the area of material accumulations, which are far-off the ingate section, can be feed by using hydraulically actuated squeezers which are common in practice.

The die-casting mold inserts in the mold frame must be rigidly supported so that elastic movements are avoided in the best way possible during the HPDC process. If this is not taken into account, the movement of a mold insert can increase the jamming effect of the solidifying casting alloy and significantly hinder demolding from the mold. With unfavorable die-casting mold construction this can lead to the jamming of the cast on the sprue side of the mold, where no ejector pins for demolding are available.

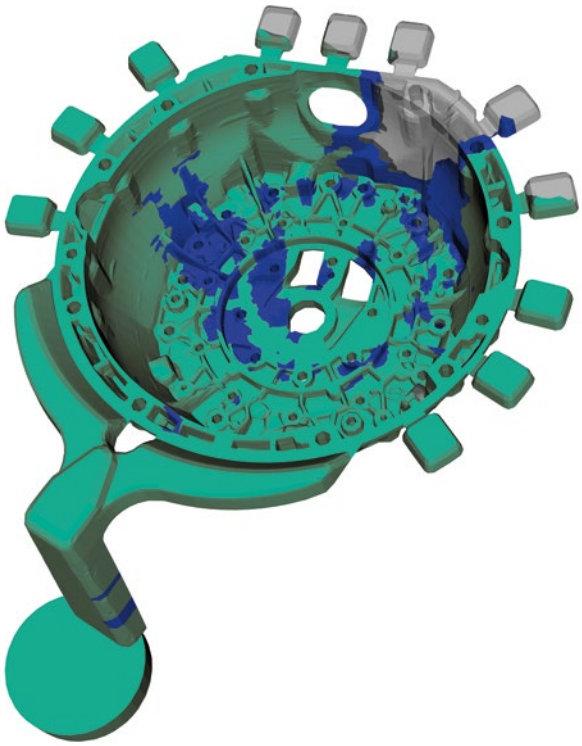

Fig. 8: Image of a simulation to reduce entrapped air in the mold due better venting

### Eight Target levels for HPDC

Fig. 9 shows eight levels of the HPDC process, which finally are necessary result in a cast suitable for welding and heat treatment.

It may be more comfortable to choose an proper alloy then to handle the different HPDC processes. Therefor also some HPDC alloys described in formers handbooks are named here.

There are higher requirements for the process of structural casts than for general purposes. Depending on your requested targets shows the eight-level-staircase for the main areas of HPDC some suggestions. We divide between dosing technique, air reduction in the cavity, melt handling and application of mold release agent.

A requested high cast quality requires on the one hand the use of high-quality die-cast aluminum alloys, also with a metallurgically proper handling of the returns. On the other hand is the consistent application necessary by die-cast fundamentals for technical cast design, such as ingate design.

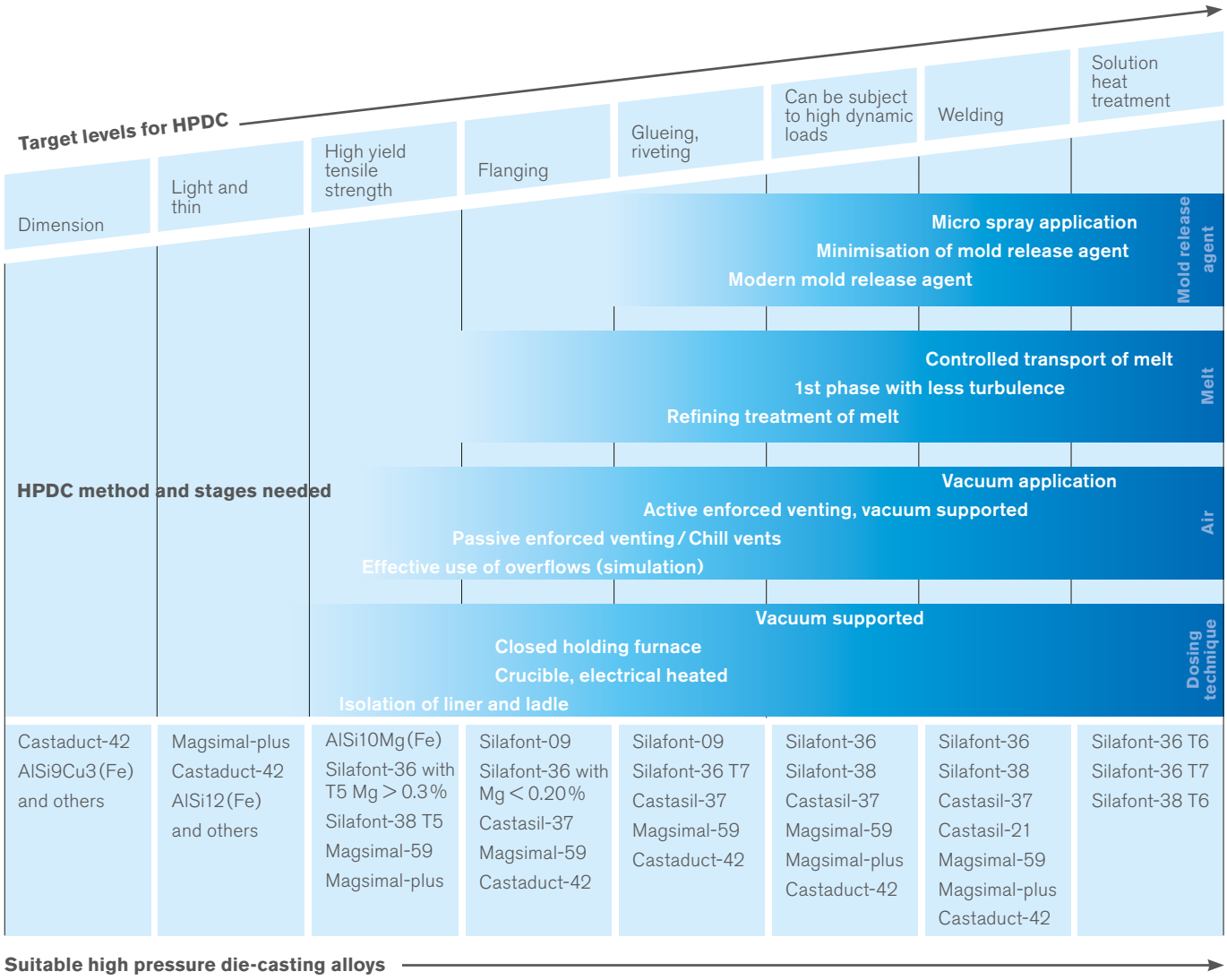


Fig. 9: Eight target levels of high pressure die-cast with details of the alloys to use and the HPDC method and stages required

## Surface coating techniques for die-casts

Maximum surface condition requirements are defined for pressure die-casts which are to be coated or anodized. This applies specifically to top-quality coatings which must meet maximum requirements, with regard to decorative appearance and resistance to corrosion for example in the automotive or aviation industry.

The following parameters have considerable influence on flawless coating or anodizing:

- Pressure die-cast design and process
- Mold design and metal flow
- Handling and machining

Here some design and processing tips are reported to help preventing detrimental influences on the coating/anodizing.

### Influence from the cast design

The cast design should have no sharp edges and small radii below 2 mm. “Thinning-out” causes running away of the coating film at the edges during baking with significantly lower coating thicknesses (Fig. 10).

Undercuts and bores always present problem areas in the frequently applied electrostatic coating technology, which can only be covered evenly with electro-dip painting (KTL).

### Influence from the mold design

At least 1 % draft angle for the AlSi-alloys and at least 1.5 % for the AlMg-based alloys should be assumed. Hot cracks may appear in thermally loaded areas of the cast with older molds. These mold crack marks and other burrs must be removed as they cause “paint thinning” on their sharp edges. Deep mold cavities without melt flow through possibility must be designed with overflows so that no air, release agent residues or any oxide skins are included in the cast during the mold filling, which may cause blister formation during baking of the coating.

### Influence from the HPDC process

Mold release agents, preferably water based, are used for smooth and easy removal of casts from the mold. Some of these burn into the cast skin. Release agents containing silicon or graphite can thus cause considerable problems. The gate area is in some cases additionally greased in order to prevent soldering to the mold due to increased thermal load. The ingate should not be in the visible area of the cast as far as possible. These lubricants also cause adhesion losses for coatings. Therefore a very economical use of these lubricants is recommended for casts to be coated.

### Surface pre-treatment

The mechanical effect of frequently applied vibratory grinding processes is often insufficient to reliably remove cast skins, so that a shot blasting process is recommended.

Heat treatments at solutionizing temperatures above 450 °C, such as T4, T6 and T7 for AlSi10MnMg, produce highly oxidized surfaces which must be considered during surface pre-treatment.

Ceramic media, such as corundum in particular, are very suitable shot blasting media. Glass beads or aluminum granules cause only slight material removal. Not suitable are metals and plastics, which cause painting adhesion losses due to the penetration of flakes into the workpiece surface. Residual iron particles also form nuclei for pitting corrosion.
When using coolants for machining, it must be taken into account that they have to be completely removed immediately afterwards by degreasing. Coolants attacking aluminum must not be used. Material compatibility and removableness of coolants must determine their selection (Fig. 11).

Fig. 10: Two-part cast for rear swinging fork for motorbike; multi-path welded structure in stiff design; powder coated

Fig. 11: Flow meter for jet fuel; chromated before coated

It is necessary to clean chemically the work piece prior to shot blasting as residues from lubricant or crack testing agents can be hammered into the workpiece surface by the shot blasting process.

Large quantities of the mold release agents and piston lubricants are particularly problematic as they cause burnt oil carbon residues on the cast. Keep this in mind especially for parts in the as-cast state.

Alkaline pickling processes for targeted roughening of the surface are not recommended for the surface treatment of AlSiMg-pressure die-casts. The high silicon content cause dark, insoluble residues during alkaline pickling. Subsequent acid pickling is then unavoidable for removing this "pickling deposit". Our AlMg alloys don't show such effect. To optimize the paint adhesion with the AlSi-alloys we suggest a chromate pre-treatment.

**Effect of baking temperatures**

Electrostatically adhering powder particles should be sintered together on HPDC at target temperatures of 120 to maximum 200 °C. A change occurs in the mechanical properties of AlSi10MnMg during the coating process starting from 150 °C after 1 hour; with Magsimal-alloys this happens only above 180 °C. Furthermore mechanical properties of Magsimal-59 and Magsimal-plus gets stable after paint bake cycle treatment with temperature above 180 °C.
Castasil-37, Castaduct-42 and Castasil-21 shows no changes.

## Joining techniques for die-casts

**Adhesive bonding**

Magsimal-59, Magsimal-plus, Castasil-37 and Castaduct-42 are die-casting alloys with the requested properties for structural application in the as-cast state. There is no dimensional correction needed due to the missing heat treatment. That gives high benefit to assembling with adhesive bonding. Additionally there is no longtime influence through our alloys, due low Cu and Zn content.

**Flanging**

AlSi10MnMg with a magnesium content of approx. 0.16 % can be used particularly for flanging technology. The designer can thus join the aluminum pressure die-casts to other materials such as steel and plastic. This can be applied as fixing but also as structural joining technology with appropriate construction design (Fig. 12). The configuration of the flanging edge mostly requires an elongation of at least 8 % on the pressure die-cast material. Therefore high internal quality requirements are set on this area of the cast. As consequence, in this kind of applications the design of the mold must guarantee good metal flow in the flanging edge, what has to be kept in mind especially with Magsimal-59 and Castaduct-42.

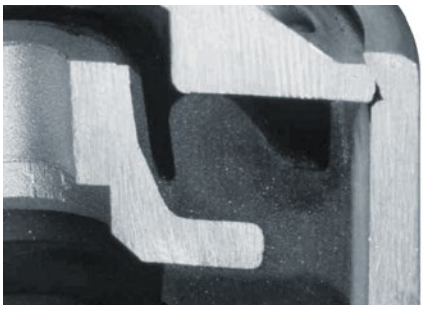

Fig. 12: Vibration damper housing made of AlSi10MnMg, with structural flanging

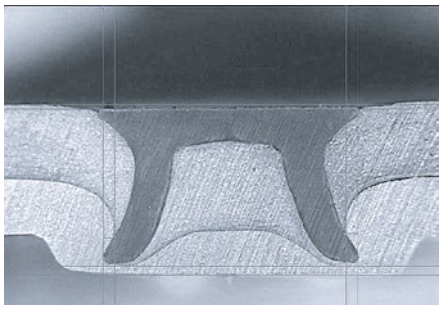

Fig. 13a: Cross section of a self-piercing riveting trial, 5 mm rivet, 1.5 mm AlMg3 sheet metal, under Castasil-37 die-cast plate in the as-cast state (F)

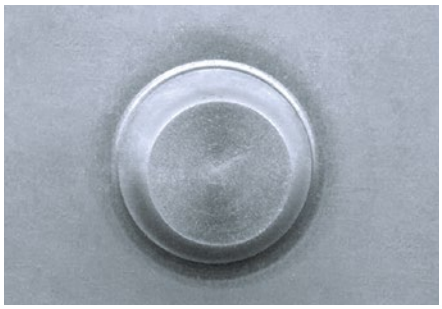

Fig. 13b: View from below

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**Self-piercing riveting**

Joints in which the cast is the lower layer in the riveting joint, have particularly high requirements concerning the absence of defects in the casting material. Figures 13a and 13b show the result of a self-piercing riveting trial in our laboratory.

It should be noted that Castasil-37 can be self-piercing riveted in the as-cast state also under these severe design conditions, i.e. using a rivet mold with flat geometry. The Castasil-37 batch used for this trial had a yield strenght of 114 MPa, an ultimate tensile strength of 255 MPa and 14 % elongation. A further improvement in deformability is achieved in temper O.

Ask for our experience in self-piercing riveting with our other alloys for structural design demands.

**Welding**

All here mentioned HPDC alloys are suitable for friction stir welding and other pressure welding methods.

The suitability of HPDC for fusion welding is highly dependent on the processes. There is no tendency for hot tearing with these die-cast alloys. Alloys, melting and die-casting methods which ensure low gas absorption and oxide impurity during HPDC are needed.

The designer may place weld seams in zones with less loading, but preferable they should also be close to the ingate, due cast quality generally is there higher.

High pressure die-casts made from Silafont-36, Silafont-38 and Castasil-37 are particularly well suited to welding, with both MIG and TIG standard methods. The S-AlSi5 or S-AlSi10 welding addition material is preferred for welded designs with AlMgSi0.5 wrought alloys.

The AlMg-based alloys, like Magsimal-59, Magsimal-plus and Castaduct-42 have a higher shrinkage rate and force than AlSi HPDC alloys. Mold release agents recently developed for work with alloy family improve both the ease of flow, i.e. ability to slide during ejection, and therefore the suitability of the high pressure die-casts for welding.

Design welding with casts made from Magsimal-59, Magsimal-plus and Castaduct-42 are undertaken with the addition material S-AlMg4.5Mn using the TIG method. Unlike the case with elongation, the mechanical properties in the heat influence zone are hardly affected. The use of S-AlSi5 in AlMg die-cast alloys would result in a decrease in elongation, and also to cracking in the weld.

| **Wall thickness** 4 mm | **YTS** [MPa] | **UTS** [MPa] | **E** [%] |
|---|---|---|---|
| Ma-59 not welded | 165 | 287 | 17 |
| Ma-59 welded | 148 | 246 | 6 |

All die-casting alloys are well suited for friction stir welding or spot welding. Spot and laser beam welding processes must take the special features of aluminum material into account.

Patented by RHEINFELDEN ALLOYS are the alloys Magsimal-59, Magsimal-plus, Castasil-37 and Castasil-21. Silafont-38 and Castaduct-42 are in status patent pending.

We would like to thank all our business partners who have provided have provided casts or photographs for this publication. Special thanks to AUDI AG for the ASF picture on the front side and RWP Simtec for a picture about casting simulation.



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