trimal®-52 – A New Aluminum Alloy for High Performance Spaceframe Construction
trimal-52® - A New Aluminum Alloy for High Performance Spaceframe Construction

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Abstract
Aluminum especially extrusions of the 6xxx series has considerable potential to make cars lighter and thus more economical. TRIMET ALUMINIUM AG has been supplying aluminum and services for the aluminum industry since 1988. TRIMET Essen produces aluminum billets for high performance profiles especially in automotive applications since 1994. Over time requirements have been changed to higher strength for profiles with lower wall thickness including better energy absorbing behavior. Therefore TRIMET and Honsel started an innovative alloy and process development to give these profiles considerably greater strength and better folding behavior under load compared to other alloys available. Extrusions made out of this new alloy, trimal®-52, fulfill the highest demands of the OEMs. This paper describes the most important aspects of the production chain of aluminum for spaceframe application from the alloy development to the casting process and at least to test results of the final product.

Introduction
Automotive applications, especially construction parts for the carbody shell, are the driving force for the development of high performance aluminum alloys and aluminum extrusions. Aluminum spaceframe constructions as shown in Figure 1 lead to an increasing demand for aluminum extrusion profiles and permanently higher aluminum property requirements. Higher strength for profiles with lower wall thickness including better energy absorbing behavior is the focus of today’s effort, Figure 2.

The Essen plant of TRIMET ALUMINIUM AG has been supplying and developing aluminum for such purposes since 1994.

Figure 1. Body in white based on a high performance aluminum spaceframe construction, Audi TT.

To fulfill today’s highest requirements it is necessary to control and develop the complete process from melting and alloying through to billet casting and homogenization right down to the thermal treated profile. To this end, TRIMET and HONSEL started an innovative alloy and development process to give such profiles improved properties.

Figure 2. Requirements of alloy properties for space frame applications.

Chemical Composition
The strengthening of 6xxx aluminum wrought alloys is determined essentially by the Mg-Si precipitates [1]. Foreign atoms or precipitations act like defects in the lattice of the Al-structure. In this type of alloy the intermetallic phase Mg2Si increases the strength. Most of these alloys established at present in Europe have a Si excess in relation to the “balanced” atomic ratio 2 Mg : 1 Si, Figure 3. Freely available Si causes a further strength increase in the solid solution state. This effect is less effective with a Mg excess [2].
Other effects of the Si:Mg-ratio are:
- Si excess increases the quench sensitivity of the alloy,
- Si excess gives more intermetallic phases on the grain boundaries, which affects the ductility negatively [2]
- with a higher Si : Mg ratio up to 1.1 the crush behavior improves.
- Newer investigations show that with a Si : Mg ratio close to 1, very good strength results can be achieved, whereby an increase in productivity with these alloys has been found e.g. by higher extrusion speed [4].

Other alloying elements must also be considered. Additions of Cu for example increase the strength but have negative effect on ductility [5]. Additions of Mn and Cr form fine dispersed phases, which can prevent the recrystallization of Al-Mg-Si alloys during hot working or heat treatment. These dispersed phases reduce the local tensions in the structure and thereby increase the ductility [5].

As further elements have to be considered, the metallurgy of such alloys is very complex. To determine the type and the amount of the high number of different phases during solidification TRIMET uses thermodynamic software. Using these tools for the development of trimal®-52 two different alloy variations were designed: one alloy with Mg excess and another with Si excess.

Cross sections from a hollow extrusion show that the alloy with Mg excess forms globulitic precipitations, Figure a). The alloy with Si excess shows plate-like precipitations which are unfavorable, Figure 4 b). This alloy has poor deformation behavior, while the alloy with Mg excess has good deformation behavior. Therefore the target magnesium/silicon ratio for the trimal®-52 was defined with Mg excess as shown in Figure 3.

![Figure 3. Target magnesium/silicon ratio for the trimal®-52](image)

Figure 3. Target magnesium/silicon ratio for the trimal®-52 [3]

![Figure 4. Precipitations in 6xxx-alloys: (left) Mg excess; (right) Si excess](image)

Figure 4. Precipitations in 6xxx-alloys: (left) Mg excess; (right) Si excess
Casting Process
The billet castings during the alloy development were carried out on a R&D-casting machine, which allows production-like castings, Figure 5. All casting parameters could be adjusted as on the production machines. The main parameters are:

- Billet diameter: 290mm
- Casting length: 7000mm
- Melt temperature: 720°C
- Casting speed: 68mm/min
- Water flow rate: 300l/min

The most important result for successful casting and extrusion of such alloys is a defect free billet. Only highest purity billets with a perfect and homogeneous microstructure can yield high performance profiles without failure caused by defects like porosity, inclusions etc. TRIMET Essen uses certified master alloys, a batch melt treatment with argon and chlorine gas, optimized settling times and a ceramic foam filter system to achieve a clean melt. The melt quality is checked with different methods, for example the PoDfa-method, [6].

Billet Homogenizing
The targets of the billet homogenizing of the trimal®-52 were:

- Best extrusion properties (high extrusion speed)
- Optimized hardening after the extrusion process (Mg and Si are completely solved when exits the extrusion die)

These targets are contradictory concerning the optimized homogenization parameters. Best mechanical properties are achieved with Mg and Si completely solved in the billet, but this yields very high extrusion forces. Therefore microstructure of the trimal®-52 should have finest possible secondary phases and small, round structured primary phases (e.g. AlFeSi) on the dendrite boundary. A schematic diagram for the cooling is visible in Figure 6. Besides a homogenizing temperature, which is high enough to solve the Mg and Si completely the cooling rates are the main influence on achieving the target microstructure.

Figure 5. R&D Casting machine for extrusion billets and slabs at TRIMET ALUMINIUM AG, Essen.

Figure 6. Precipitation structure depending on temperature and cooling rates, [7].

An adopted homogenizing and cooling process for the billet yields an microstructure like visible in Figure 7. The secondary Mg2Si phases are homogeneous and fine and the primary phases on the grain boundaries are well spread and round.
Extrusion Process

The increasing demands on complex extrusion designs conclude a high risk of die failure during the extrusion operation. The number of pot holes in a die increases and makes a die less stiff. Small mandrels move, can get deformed or break if the stresses are too high.

With today's FEM tools it is possible to calculate the die stress and the deformation of a die; Figure 8. A critical design can be identified before an expensive die fails. It is also possible to see if the die design allows a uniform metal flow; Figure 8.

In order to produce aluminum extrusions with good mechanical strength it is important to control the thermal treatment very accurately.

The objective of quenching after the extrusion is to preserve the solid solution [7]. The highest strength attainable and the best combination of strength and toughness are those associated with the most rapid quenching rates. With a higher cooling rate the degree of distortion of an extrusion increases. In addition, the quench rate depends on the wall thickness of the extrusion. Because of these effects, special understanding of this process is necessary to produce good extrusion qualities.

Extensive ageing examinations were carried out to find the optimum adjustment between strength, ductility and crash behavior respectively. Another observation was made, that the influence of the homogenizing procedure cannot be neglected, Figure 9.
Results
The cooperation between TRIMET and Honsel while developing a new aluminum alloy for high performance space frame constructions resulted in the new trimal®-52. This alloy fulfils the current market requirements. The main mechanical properties are:
- \( \text{Rp0,2} \): 281 – 330 MPa
- \( \text{Rm} \): > 305 MPa
- \( \text{A5} \): \( \geq 10\% \)

The crash performance of the alloy is excellent, Figure 10. This is a very important property for the use in car body shells.

All these properties result in the possibility of weight reduction of cars and this reduces the gas consumption and CO2 emission.

Conclusions
Complete, detailed and very exact control of the production process from alloying over casting up to the extrusion process with extrusion and homogenizing combined with research and development in each process step leads to continuous advancement of aluminum alloys and their properties. Modern development software tools like thermodynamic calculation, especially, open up new fields of development.

The trimal®-52 alloy shows that the 6xxx alloys especially are very promising for further applications with highest requirements. With this new alloy it is possible to reduce the weight of the cars and so reduce the gas consumption and CO2 emission.

In the future the aluminum industry has to work out new and advanced alloys for the future requirements of the automotive industry and all other customers. Customers are already looking for aluminum wrought alloys with higher yield strength and excellent crush behavior. With the approved co-operation of a modern and innovative cast house and extrusion plant this target can be achieved.

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Figure 10. Excellent crush behavior of extrusions with the new high strength aluminum alloy trimal®-52.
References