

PROGRESS IN DUCTILE ALUMINIUM HIGH PRESSURE DIE CASTING ALLOYS FOR THE AUTOMOTIVE INDUSTRY

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Today the die casting process is used to cast parts with high quality requirements such as engine cradles, cross members and nodes for space frame construction.

This has presented the challenge to design alloys with superior mechanical properties. For crash relevant parts requiring high ductility (elongation > 12 %) one option to meet these properties is by heat treating a low iron Al-Si alloy to a T4 or T7 temper. However heat treatment can lead to part distortion and blistering resulting in higher costs for the producer. The second option is Al-Mg alloys type which fulfill these requirements in the as-cast state but the alloys are not easy to cast. Research was started using the easy to cast Al-Si alloy system targeting a high elongation (> 12 %) and yield-strength (> 120 MPa) already in temper F and not showing any long term aging behavior. This paper will discuss the technical progress which began in the early 1990ies, gaining in importance with the first series space frame Aluminum car, continuing with structural parts applied in the as-cast state and approaching a future with an increasing amount of light weight components replacing steel and heat treated Aluminum designs.

PAROLE CHIAVE: high-pressure die casting alloys, ductility in the as-cast state, automotive, ductile al-alloys

INTRODUCTION

The automotive industry has provided the driving force for the development and production of new die casting alloys. From a technical point of view the field of application for standard aluminium alloys is limited. These alloys are mainly used for parts with a simple requirement profile, usually low weight and a certain yield strength. The qualitative evaluation in Fig. 1 shows the limits of standard alloys.

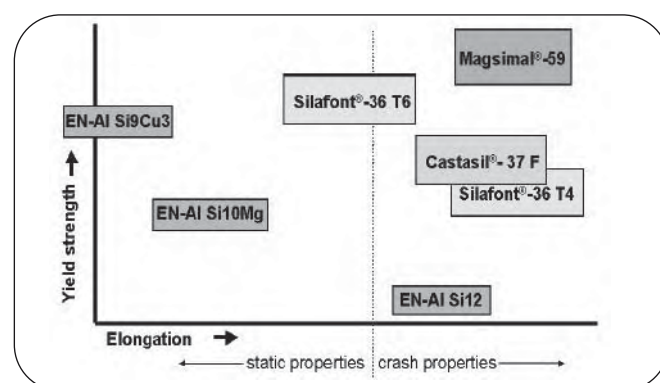
An Al Si9Cu3-type (226) is mainly used for parts without any requirements concerning ductility or good resistance to corrosion. An Al Si12-alloy provides a certain ductility when cast into a permanent mould but has no remarkable yield strength. Somewhere in between other compromises may be found.

SILAFONT®-36

Aluminium Rheinfelden presented Silafont®-36 for the first time in 1994 as the first ductile aluminium alloy for high-

pressure die-casting. The chemical composition is shown in Tab. I.

Silafont®-36 is based on the aluminium-silicon system with its known good casting abilities for high-pressure die-casting. The manganese content is kept in a range of 0,5 to 0,8%

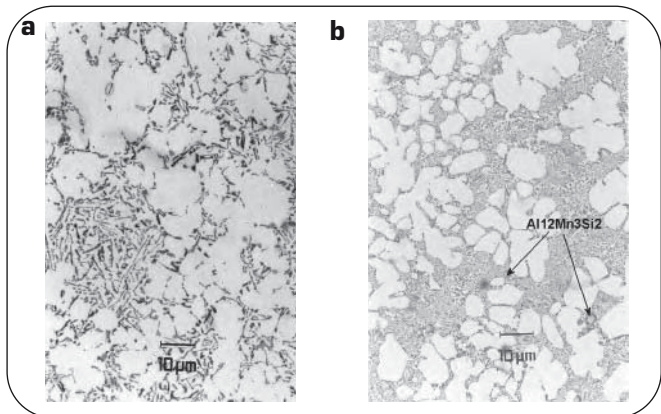


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Fig. 1

Ranking of aluminium alloys focussing on the mechanical properties.

Classificazione delle leghe d'alluminio standard e di quelle a marchio Rheinfelden sulla base delle loro caratteristiche meccaniche.

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Fig. 2

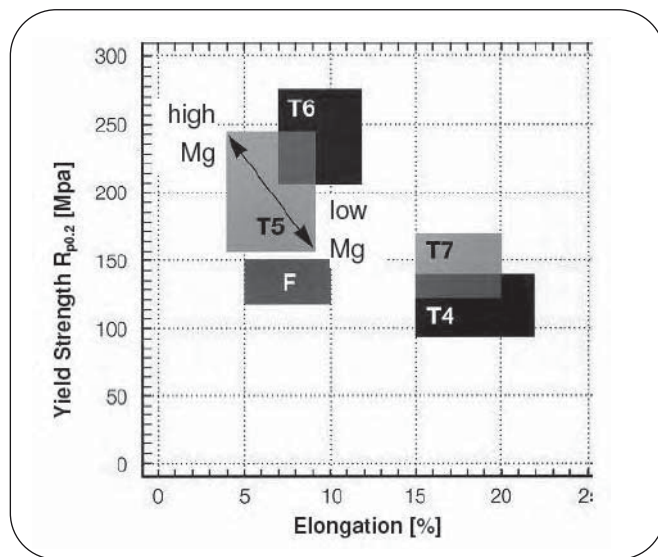
a: Al Si10Mg standard material, sample thickness 4 mm, no Sr modification, 5% elongation in temper F b: Silafont®-36, sample thickness 4 mm, Sr-modified, 10 % elongation in temper F.

a: Una lega Al Si10Mg standard. Spessore di parete di 4 mm, non modificata allo Sr; 5% di allungamento allo stato grezzo F. b: Silafont®-36, spessore di parete di 4 mm, modificata allo Sr; 10 % di allungamento allo stato grezzo F.

weight percent. Below the cast part may stick to the die, above the elongation may suffer from the growing manganese phases. Magnesium is added for the yield strength. Low Mg-contents make a ductile alloy with a lower yield strength, whereas high contents bring up the yield strength and decrease the elongation.

Titanium has the typical grain refining effect and increases castability and mechanical properties. 100 to 200 ppm strontium are added to modify the eutectic. Fig. 2 shows the microstructures of a not modified eutectic on the left and Sr-modified eutectic on the right hand side. The modified eutectic is considerably finer which has a positive influence on the elongation.

Based on the mechanical properties in temper F, as a result of the chemical composition and the microstructure achieved by metallurgical means, Silafont®-36 offers a wide variety of mechanical properties according to the heat treatment and the Magnesium content (see Fig. 3). For



▲
Fig. 3

Mechanical properties of Silafont®-36 for different heat treatments.

Caratteristiche meccaniche di Silafont®-36, in funzione del contenuto di magnesio e del trattamento termico.

applications requiring high ductility a T4 (solution treatment, quenching & natural ageing for at least six days) or a T7 (solution treatment, quenching & overageing) temper are recommended. For a high yield strength a T5 (quenching after ejection & artificial ageing) or a T6 (solution treatment, quenching & artificial ageing) temper may be adequate.

SOME APPLICATIONS IN SILAFONT®-36

The first major application for Silafont®-36 were nodes produced in high-pressure die casting for a space frame construction of an upper class passenger car. The main requirements were a medium yield strength, weldability, corrosion resistance and most of all ductility. Today Silafont®-36 may be considered as an alloy known all over the world. A more recent application is shown in Fig. 4.

Here we can see the engine cradle of a high volume middle

	Si	Fe	Cu	Mn	Mg	Zn	Ti	Be	Others
min	1,8			0,5	5,0				
max	2,6	0,2	0,05	0,8	6,0	0,07	0,20	0,004	0,2

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Tab. 1

Chemical composition of Magsimal®-59 in weight-%.

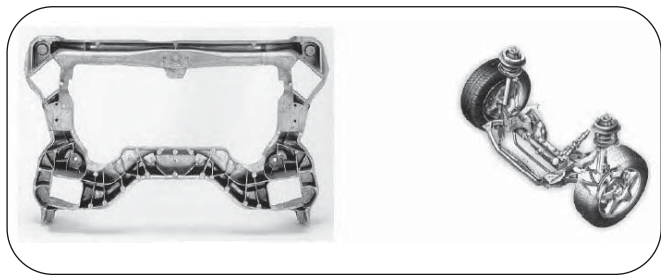
La composizione chimica di Magsimal®-59 in peso %.

	Si	Fe	Cu	Mn	Mg	Zn	Ti	Sr	Others
min	8,5			0,35				0,006	
max	10,5	0,15	0,05	0,60	0,06	0,07	0,15	0,025	0,2

▲
Tab. 2

Chemical composition of Castasil®-37 in weight-%.

La composizione di Castasil®-37 in peso %.



▲
Fig. 4
Engine cradle for a middle and upper class passenger car.
Supporto motore di un'auto di categoria medio-alta.

class car in temper O. A similar part is used in a luxury car in temper T6. The assembly situation on the right hand side with the surrounding front suspension shows clearly that this part has to provide a good deformability in case of a crash and a certain yield strength in order to carry the engine (not shown) mounted onto the cradle. The mechanical properties are enhanced by upgrading the die casting process with a vacuum system. The necessary rigidity is provided by ribs that can be seen in the lower part of the casting.

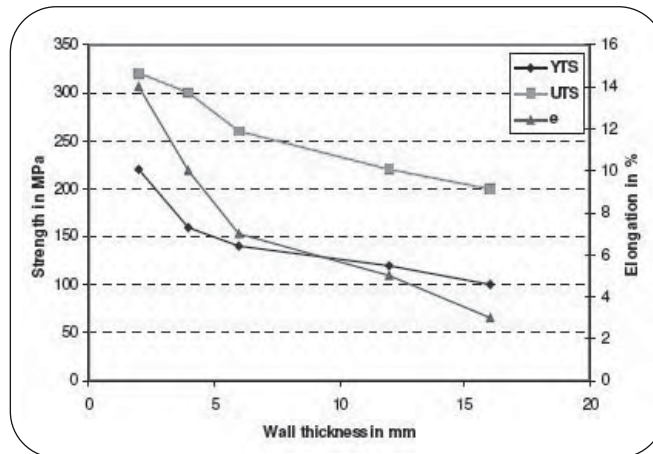
Although exposed to heavily corrosive conditions the cradle does not require any surface protection. It measures 0,92 m by 0,17 m by 0,17 m and weighs 10,2 kg.

MAGSIMAL®-59

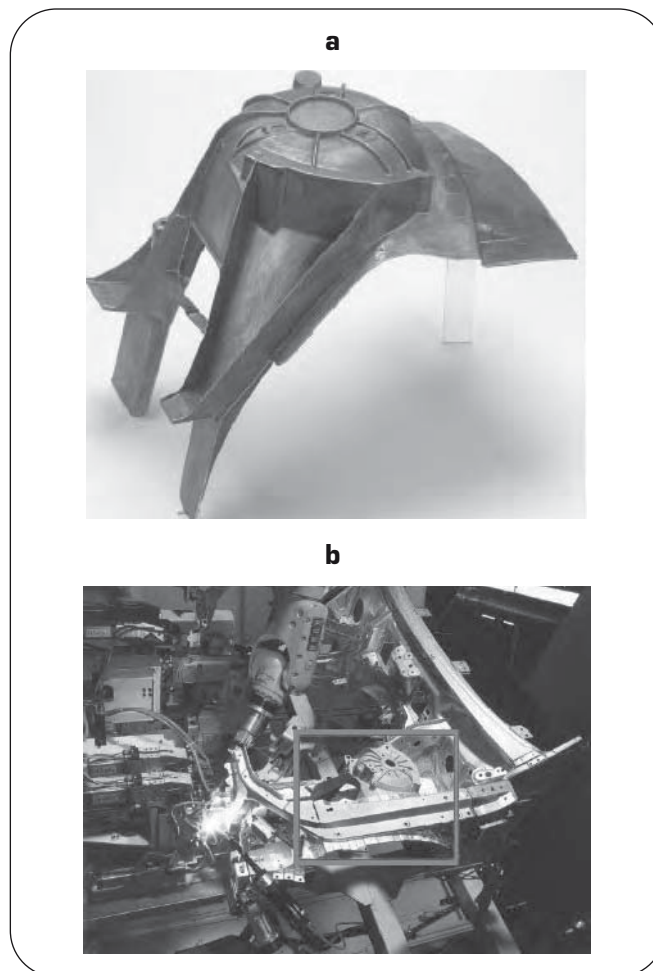
In 1996 an alloy was presented to the market, which was unusual for high-pressure die casting at that time: the AlMgSi-type Magsimal®-59. So far this type of alloy type had been mainly used for permanent mould casting and was especially known for its excellent resistance to corrosion even in sea water. However in addition to that it offers further properties and abilities when used in high-pressure die casting which make it superior to many other alloys. In Tab. 1 the chemical composition is shown.

Other than most alloys for high pressure die-casting Magsimal®-59 contains five to six percent Magnesium and roughly two percent of Silicon. A surplus of Magnesium and low Copper and Zinc contents maintain the excellent resistance to corrosion. Iron is kept low to keep up the elongation. Beryllium is added to reduce dross during the melting process. Together with a quick solidification a very fine microstructure consisting of an α -solid solution and 40% Mg₂Si-eutectic is created with superior mechanical and fatigue properties in temper F. As the fineness of the microstructure depends on the solidification velocity, the geometry of the casting has an influence on the mechanical properties. The influence of the wall thickness on the mechanical properties is shown in Fig. 5.

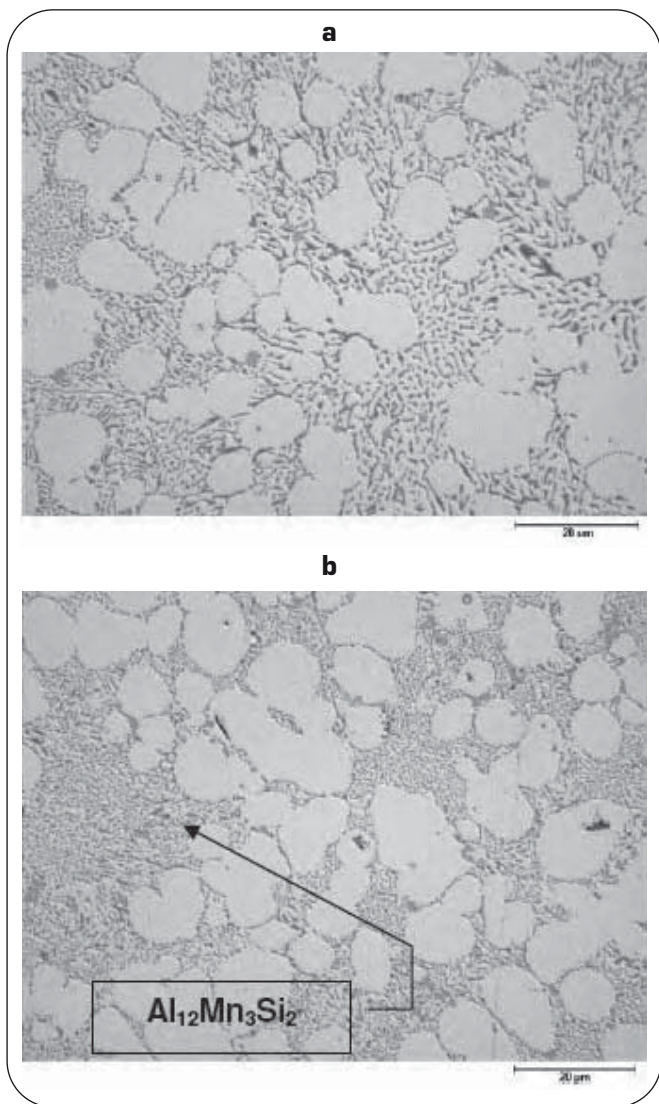
The thinner the wall thickness is, the higher both yield strength and elongation are because the microstructure becomes finer. For the designing engineer this behaviour of increasing properties with decreasing wall thicknesses has advantages, because a thin and light design promotes the performance of the material. However some recommendations looking at the complexity of the design have to be taken into account due to the higher shrinkage of this alloy type. The die design requires larger radiuses and drafts



▲
Fig. 5
Mechanical properties of Magsimal®-59 as a function of the wall thickness.
Le proprietà meccaniche di Magsimal®-59, in funzione dello spessore di parete.



▲
Fig. 6
Shock tower of the new upper middle class car – a) casting in Magsimal®-59, b) front structure in Aluminium during assembly.
Duomo della sospensione di una nuova auto di classe medio-alta. a) getto in Magsimal®-59, b) parte frontale del telaio durante l'assemblaggio.



▲
Fig. 7

a) microstructure of an AlSi9Mg standard material, 3mm wall thickness b) Castasil®-37 microstructure, 3 mm wall thickness.

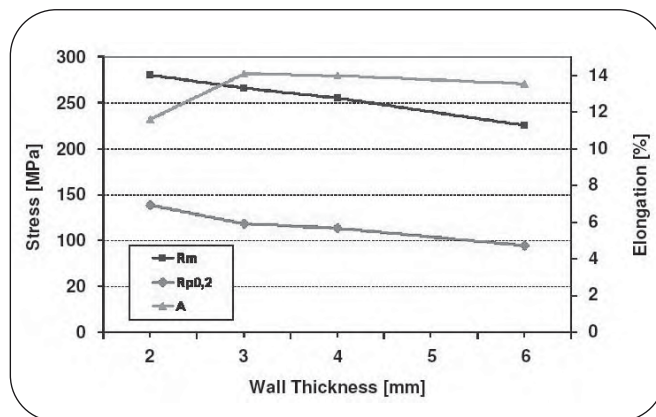
a) Microstruttura di una lega AlSi9Mg standard. Spessore di 3 mm. b) Microstruttura di Castasil®-37. Spessore di parete di 3 mm.

compared to an AlSi-type. None the less Magsimal®-59 with its excellent properties in temper F may substitute applications in AlSi requiring a heat treatment causing distortion and straightening of the parts.

SOME APPLICATIONS IN MAGSIMAL®-59

Magsimal®-59 is an excellent material for die castings, which have to resist high static and alternating loads and provide a good ductility at the same time. Typical applications are structural and suspension parts in passenger cars. Fig. 6 shows the shock tower of an upper middle class car with a completely new concept.

With the goal to spread the weight of the vehicle evenly on front and back wheels, the front sub-frame is entirely designed in Aluminium. The shock tower is a structural part where the suspension strut is connected. So this part



▲
Fig. 8

Mechanical properties of Castasil®-37 in temper F. Caratteristiche meccaniche di Castasil®-37 allo stato grezzo.

has to resist the static load from the car weight and the dynamic shocks coming from the suspension. The part is designed with thin wall thicknesses to receive the required yield strength and at the same time providing a high elongation for a good crash behaviour. The cast part is connected to the surrounding profiles and wrought Aluminium parts by gluing, self-pierce-riveting and MIG-welding. Due to the excellent corrosion resistance the part does not require a paint coating.

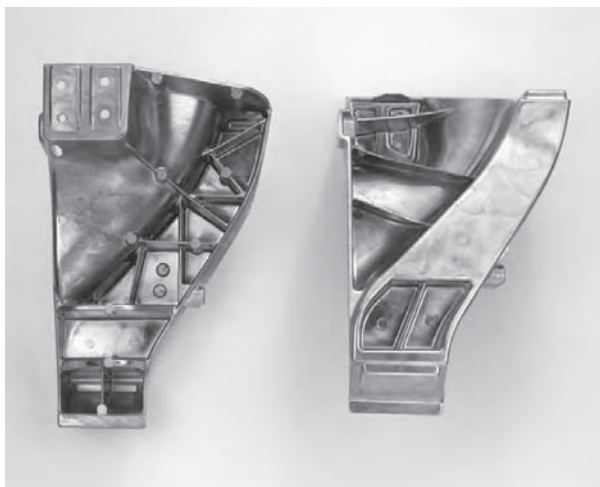
CASTASIL®-37

With the development of Castasil®-37 Aluminium Rheinfelden is working on another alloy for high pressure die casting applications in passenger cars with complex designs requiring high ductility and a medium yield strength. These are for example nodes and structural components in space frames or sub-frames, usually with thin wall thicknesses and complex and rigid geometries. So far these types of parts are mainly cast in AlSiMg-type alloys and solution heat treated to receive the suiting properties. However solution heat treatment causes blistering and distortion of the parts, which have to be straightened in an additional process step. Because of their complex designs these parts are difficult to cast in an AlMg-alloy. So the goal for the Castasil®-37 is to provide an easy to cast AlSi-alloy with at least 12 % elongation and 120 MPa yield strength in temper F. Since engine powers and hence temperatures have been going up during the past years an alloy is needed which shows no long term aging behaviour in a high temperature environment. High resistance to corrosion has to be met by the way.

Castasil®-37 contains 8,5 to 10,5 percent silicon, which makes the excellent castability, typical for this kind of alloy. Iron is kept low to maintain ductility, copper and zinc likewise to prevent corrosion. Manganese substitutes iron and avoids sticking to the die. Strontium provides the known modification of the eutectic and the linked ductility. Other than most alloys so far in this field of application, Castasil®-37 has a low amount of magnesium. This makes an even finer eutectic in addition to the Sr-modification and avoids a long term aging behaviour.

In Fig. 7 the microstructures of a standard material and Castasil®-37 are shown for high pressure die cast 3 mm sample

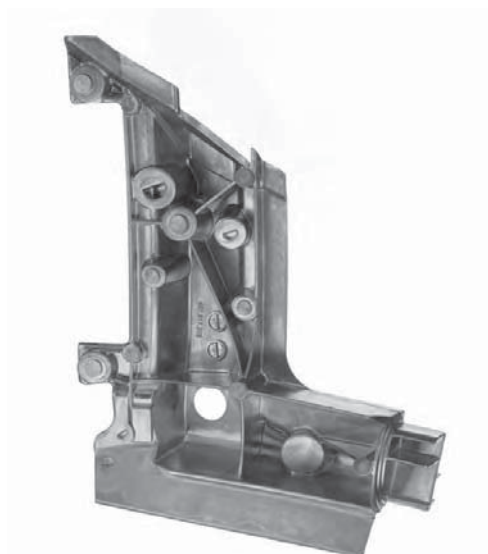
a



b



c



plates.

In the microstructure of an AlSi9Mg standard material coarse regions of the eutectic prevent the material from reaching highest levels of elongation in the as cast state.

These coarse regions are due to magnesium precipitations forming an Mg₂Si phase.

Without magnesium this is avoided and the eutectic appears even finer, as shown on the right hand side. This makes the additional step towards higher elongation in temper F. Looking at the mechanical properties, shown in Fig. 8, a slight influence of the wall thickness can be stated. Here it was examined for wall thicknesses from 2 to 6 mm.

The yield strength decreases with an increasing wall thickness. This is due to the slower solidification in larger cross sections and may be compensated by a higher cooling of the die. The elongation shows a different behaviour. From 2 to three millimetres wall thickness it increases up to 14 percent in temper F where it remains up to 6 mm of wall thickness. The lower elongation in thin walls is probably due to the stronger impact of casting defects in a small cross section.

SOME APPLICATIONS IN CASTASIL®-37

Typical castings for Castasil®-37 have complex designs and require high ductility and a medium yield strength, good deformability, good resistance to corrosion and stable mechanical properties when operating at elevated temperatures.

In Fig. 9 the Space-Frame nodes of the Lamborghini Gallardo Spyder are shown. Die cast nodal points are decisive for special rigidity in the ASF bodywork of the open-top Spyder. The high yield strength of Castasil-37 in the as-cast state enabled the very economic production of these weldable nodes. The minimum required elongation was of over 7% on the casting. With the use of Castasil-37 a weight reduction of about 10-15% in comparison with traditional high-pressure die casting alloys was possible. In addition to this even a better Rigidity/Weight ratio as the steel one was achieved. With a material providing the desired properties in temper F or with a single step heat treatment a straightening process becomes obsolete.

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Fig. 9

The high-pressure die cast nodes in Castasil-37 for the ASF of the Lamborghini Gallardo Spyder

a) rear connection node

b) internal A-pillar reinforcement

c) folding-top struts.

I nodi pressocolati in Castasil-37 per l'ASF della Lamborghini Gallardo Spyder

a) nodo di connessione longherone posteriore

b) rinforzo montante anteriore

c) angolo superiore del parabrezza.

ABSTRACT

CARATTERISTICHE DI ALLUNGAMENTO SUPERIORI NELLE LEGHE DI ALLUMINIO DA PRESSOCOLATA E LORO POSSIBILI APPLICAZIONI

Keywords: alluminio e leghe, metalli, fonderia pressocolata

Il processo di pressocolata moderno è calibrato per ottenere getti dagli elevati standard qualitativi come supporti motore, traverse e nodi per strutture Space-Frame. Questa sfida è il punto di partenza per lo sviluppo di leghe dalle performances meccaniche superiori, con particolare riferimento alla caratteristica di allungamento a rottura.

Diversi sono gli ambiti di ricerca per il raggiungimento di tali obiettivi prestazionali, particolarmente importanti per il buon comportamento a crash: composizione chimica, trattamento termico e condizioni di solidificazione.

Questa memoria ripercorre le tappe dei progressi tecnici iniziati negli anni '90 e concretizzati nella prima serie di automobili a struttura Space-Frame. Più recentemente l'attenzione si è rivolta a parti strutturali montate allo stato grezzo, per orientarsi poi verso componenti leggeri che sostituiranno sempre più spesso strutture in acciaio o in alluminio trattato termicamente.

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