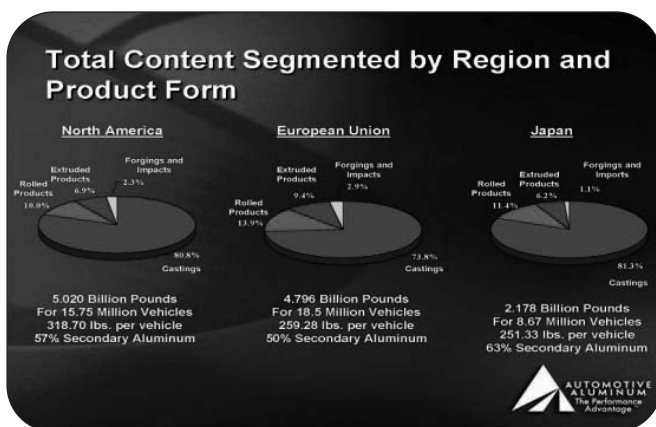


SILAFONT-36, THE LOW IRON DUCTILE DIE CASTING ALLOY DEVELOPMENT AND APPLICATIONS

Anna Zovi, Federico Casarotto

Silafont®-36 (AlSi9MgMn) was the first successful application of a low iron die-casting alloy for the automotive market. Key elements concerning the alloy development beside silicon and the modifying strontium are manganese, which avoids sticking to the die and forms globulitic intermetallic phases that provide high ductility, and magnesium, which determines the yield strength and ultimate tensile strength of the alloy. Optimum limits for manganese providing high ductility and good ejection behaviour were studied. Mechanical properties as a function of magnesium were shown with focus on very low magnesium content, which resulted in an alloy without any long-term aging behaviour. This paper presents the main features of the alloy, providing an overview on the new casting applications for the automotive sector.

KEYWORDS: High-pressure die-casting alloys, AlSi alloys, modification, ductility, low iron alloys, heat treatment, Silafont-36



▲
Fig. 1

Production volumes and types of products assembled on means of transport produced in Europe, North America and Japan.

Volumi di produzione e tipi di prodotti assemblati su mezzi di trasporto prodotti in Europa, nord America e Giappone.

Anna Zovi, Federico Casarotto
Aluminium Rheinfelden GmbH

INTRODUCTION

The driving force for the development and production of new die casting alloys is the automotive industry. Between 1990 and 2000 the aluminium content of passenger cars built in Western Europe has risen from 50 to 100 kg per car. This is an average annual consumption growth of 5 kg per car, which is nearly 7%. In 2001, 76 % of the aluminium castings produced were used by the automotive industry. The main production process used is high-pressure die-casting with a share of 70%.

The figures of 2006 confirm this trend with a continuously increasing use of aluminium in the transport sector, frequently to the detriment of steel.

North America is still the main cause of this phenomenon, with about 145 kg per vehicle, followed by Europe and Japan, respectively with averages of 118 and 114 kg per vehicle (Fig. 1).

Since the development of low iron die casting alloys, started in 1992, they have gained a market of approx. 25,000mt of ductile castings in 2002. The predominant alloy in use is Silafont-36, because of its ease of handling in the cast house, excellent castability, outstanding mechanical properties and good welding characteristics with all standard processes. Some examples of applications will be shown to demonstrate the capability of this alloy.

Besides silicon, manganese and magnesium have the

		Si	Fe	Cu	Mn	Mg ¹⁾	Zn	Ti	Sr	P	Other Each	Other Total
INGOT	min.	9,5			0,50	0,15		0,04	0,010			
	max.	11,5	0,12	0,03	0,80	0,50	0,07	0,15	0,020	0,001	0,03	0,10
CASTIN	min.	9,5			0,50	0,10		0,04	0,010			
	max.	11,5	0,15	0,03	0,80	0,50	0,07	0,15	0,015	0,001	0,03	0,10

1) Depends on the desired properties

▲
Tab. 1

Diffusion constants and activation energies for the considered elements in the ferrite, austenite and liquid phases.

Parametri di diffusione degli elementi considerati nelle fasi ferritica, austenitica e liquida.

Trial	Si	Fe	Cu	Mn	Mg	Zn	Ti	Sr [ppm]	P [ppm]
1	10,3	0,08	0,002	0,044	0,20	0,01	0,07	174	4
2	10,2	0,10	0,002	0,183	0,20	0,01	0,07	155	7
3	10,1	0,15	0,001	0,381	0,19	0,01	0,07	135	4
4	10,4	0,13	0,001	0,530	0,19	0,01	0,07	157	7
5	10,4	0,13	0,001	0,599	0,19	0,01	0,07	142	6
6	10,4	0,11	0,001	0,809	0,18	0,01	0,07	145	4
7	10,3	0,11	0,001	1,285	0,19	0,01	0,07	140	4

▲
Tab. 2

Chemical composition of the trials with different Manganese content, wt. %.

Composizione chimica delle prove con differenti contenuti di manganese, % in peso.

most important influence on resulting properties. Experiments were carried out to optimise the manganese content and to evaluate magnesium content to improve ductility.

GENERAL CHEMICAL COMPOSITION

In Tab. 1, the standard chemical composition is listed. Silicon content between 9,5 to 11,5% offers good castability and excellent die-filling capabilities. This is important when large parts are cast or when complicated die designs have to be filled. Since silicon expands during solidification, lower shrinkage behaviour and hot tearing tendencies are avoided compared to other alloys systems. The eutectic silicon is modified by strontium. This is very important for ductility because strontium additions change the silicon morphology from a blocky or lamellar type into a more coral like form. Strontium will enhance hydrogen pick-up in the melt requiring an efficient melt cleaning device such as impeller technique. This will keep hydrogen content low decreasing porosity and providing good weldability.

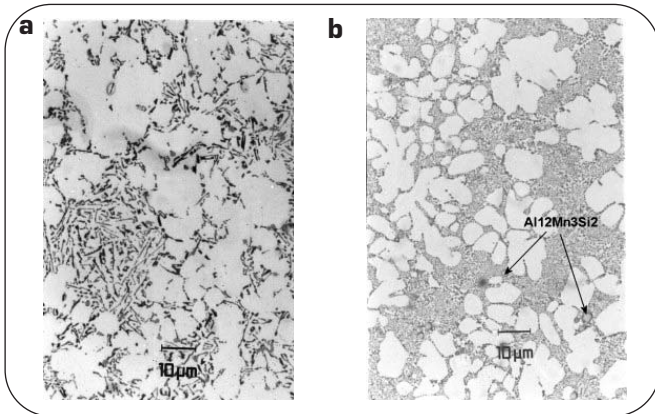
Although the die casting process provides a high cooling rate, the strontium modified structure leads to higher elongation as can be seen in figure 2a and 2b. The samples were taken from 4 mm die-cast plates. By adding strontium in the range of approximately 100 – 200 ppm, the elongation was increased from 5% to 10%.

The iron content is kept below 0,12% to minimize the formation of AlFeSi-phases that appear as needle-like shapes in the cast microstructure. Because of their morphology, strength, elongation and fatigue behaviour will deteriorate and will promote the initiation of cracks when placed under load. In place of iron, manganese is used to provide good ejection behaviour and reduced die soldering. Manganese forms Al₂Mn₃Si₂ type phases [1], which appear as globulitic particles in the microstructure, as seen in Fig. 2b. Magnesium determines the mechanical properties and aging behaviour, which will be discussed later.

INFLUENCE OF MANGANESE ON THE MECHANICAL PROPERTIES OF SILAFONT-36

It was established in the literature [2], that manganese lowers ductility in an AlSiMg alloy when its content exceeds 0,2%. For this reason, manganese was not recommended as an addition to high-pressure die-casting alloys to substitute iron or as a combination with iron.

To get a better understanding of the performance, a series of tests were carried out with different manganese content ranging from 0,04% to 1,2%. The chemical composition that was used is shown in Tab. 2. The iron content was kept below 0,15%. The magnesium content was 0,19% on average, which is the most common level in current applications. Strontium content was between 130



▲
Fig. 2

a: Microstructure of an AlSi10Mg alloy, Temper F, not etched. Test plate 4 mm wall thickness, 5% elongation.
b: Microstructure of Silafont-36, Temper F, not etched. Test plate 4 mm wall thickness, 10% elongation.
a: Microstruttura di una AlSi10Mg, stato grezzo, non attaccata. Piatti con spessore di 4 mm, 5% di allungamento.
b: Microstruttura di Silafont-36, stato grezzo, non attaccata. Piatti con spessore di 4 mm, 10% di allungamento.

to 170 ppm to establish a good modification of the eutectic silicon.

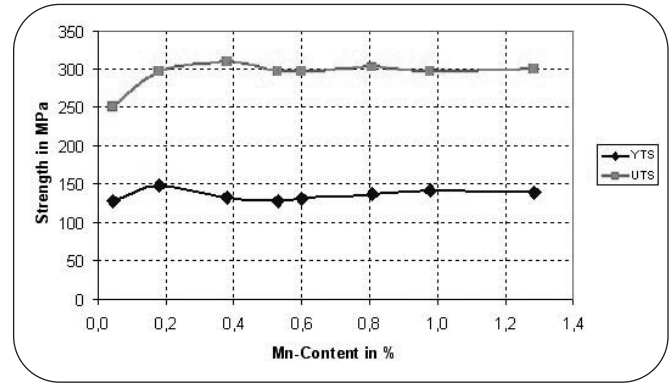
The test samples were cast on a 400 t Bühler B machine with a forced venting system. A four cavity die was used with standard casting conditions i.e. melt temperature 710 °C – 720 °C, density index of the melt <1% (80 mbar test), die temperature 200 °C both sides, die lubricant dilution 1:180, gate velocity 30 m/s to 40 m/s. The test sample had a cross section of 3 mm x 10 mm in the gauge length which meets DIN 50 125 pattern E standard. The samples were tested 2 days after casting to make sure that they were in a stable condition. The samples were tested in Temper F (as cast) and in the T6 condition with the following parameters: solution heat treatment 520 °C for 1h, quenching in water and then artificially aged at 160 °C for 6 h.

RESULTS

First, it must be stated that in the absence of manganese, sticking was very apparent even though the die was not a complicated design. The test results yielded from this composition are based only on a few samples and have limited statistical evidence. The ejection behaviour improved with the addition of manganese and at levels exceeding 0,4% the desired behaviour appeared. The results are based on 12 to 16 tests.

In the as-cast state there is only a slight difference in ultimate tensile strength and yield strength with varying manganese content. This can be seen in Fig. 3. The same behaviour appears in Fig. 4 with the T6-treated samples. Only samples with no manganese showed a different behaviour. This might be caused by the very poor ejection behaviour as described above. The parts had cracks or marks on the surface and the heat treatment may have caused surface damage leading to poor results.

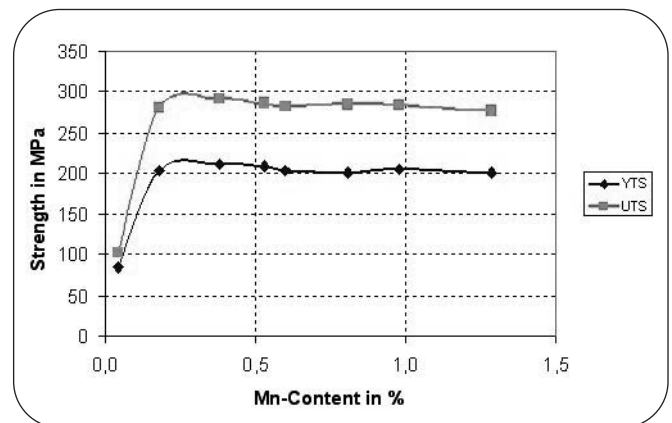
The elongation, as seen in Fig. 5 for both conditions, is showing a different behaviour. In both cases without any



▲
Fig. 3

Mechanical properties as a function of manganese content, Temper F.

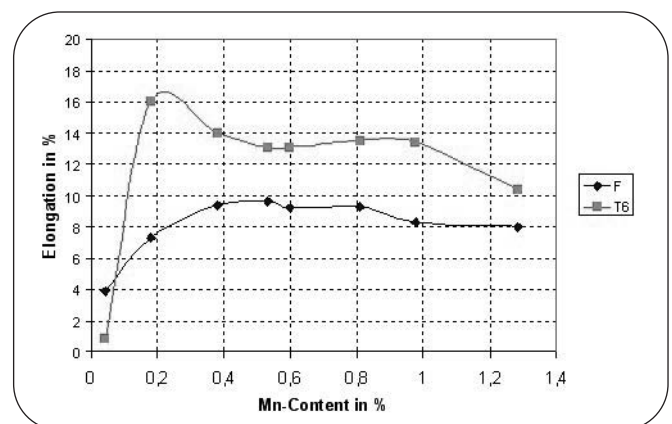
Proprietà meccaniche in funzione del contenuto di manganese, stato grezzo.



▲
Fig. 4

Mechanical properties as a function of manganese content, Temper T6.

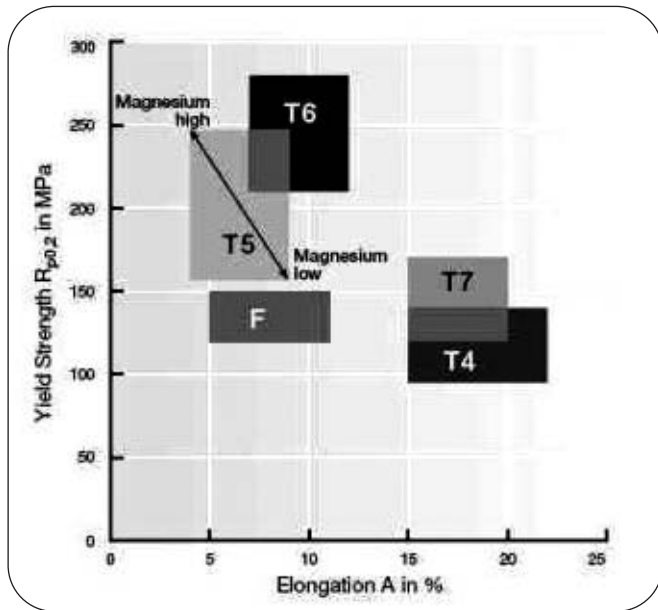
Proprietà meccaniche in funzione del contenuto di manganese, stato T6.



▲
Fig. 5

Elongation as a function of manganese content, Temper F and T6.

Proprietà meccaniche in funzione del contenuto di manganese, stato grezzo e T6.



▲
Fig. 6

Mechanical properties of Silafont-36, depending on Mg content and heat treatment.

Proprietà meccaniche di Silafont-36 in dipendenza dal contenuto di Mg e dal trattamento termico.

manganese, there are poor values of elongation due to poor ejection behaviour. In the as-cast state there is a steady elongation with a manganese content of >0,4%. Even with high manganese, the elongation is still above 8%, but the optimum content was found to be between 0,5% and 0,8%. The elongation for the heat-treated condition is different. The highest value was measured at 0,2% Mn followed by a constant elongation of 12% to 14% over a range of 0,4 to 1,0% Mn. So the optimum range for stable condition is again between 0,5% and 0,8% Mn. The differences in elongation with varying manganese may be caused by the solution heat treatment. This could be explained by the slight tendency of the manganese intermetallic phases to globulize during solution heat treatment. It could be concluded that in a high elongation matrix these particles could have a higher impact on ductility than in the as-cast state.

INFLUENCE OF MAGNESIUM ON THE MECHAN-

Heat	Si	Fe	Cu	Mn	Mg	Zn	Ti	Sr [ppm]
1	10,2	0,09	0,001	0,60	0,003	0,005	0,081	126
2	10,0	0,09	0,001	0,60	0,020	0,005	0,080	121
3	10,5	0,10	0,002	0,60	0,040	0,006	0,084	150
4	10,3	0,09	0,002	0,59	0,082	0,005	0,088	120
5	10,3	0,09	0,002	0,61	0,102	0,005	0,084	120

▲
Tab. 3

Chemical composition for trials with different Magnesium content, wt. %.

Composizione chimica per le prove con diversi contenuti di magnesio, % in peso.

ICAL PROPERTIES OF SILAFONT-36

Currently, there are four versions of Silafont-36 in use:

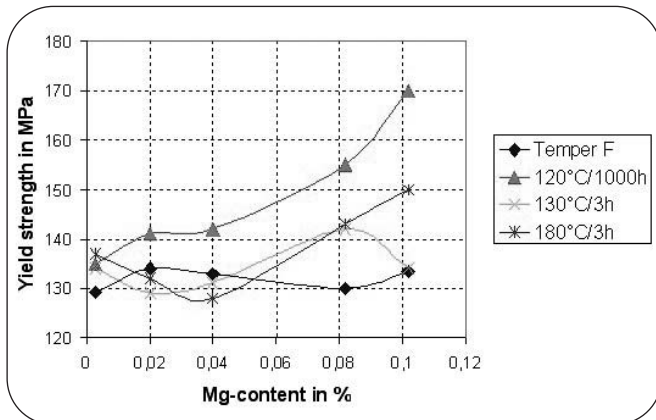
- 0,13 – 0,19% Magnesium for crash relevant parts and connecting techniques such as flanging. The parts were heat treated for increasing ductility or to avoid long term natural aging. Examples include nodes or damping parts where the damping insert is fixed using flanging technique.

- 0,18 – 0,24% Magnesium for safety parts with medium requirements on yield strength, good fatigue properties and crash relevant properties. An example would be the engine cradles. These parts also have to be heat treated to meet the desired requirements.

- 0,24 – 0,35% Magnesium for parts where high yield strength is required in combination with good impact properties such as steering racks or end plates. High screw forces should be possible for mounting parts together.

- 0,28 – 0,35% Magnesium for structural components requiring heat treatments with air quenching after solutionizing.

An overview concerning the properties of Silafont-36 in the as-cast state and after several heat treatments is shown in Fig. 6 [3]. A lower magnesium content (<0,13%) is not in use right now. On the other hand side material properties will change over time, displaying the influence magnesium has on the aging mechanism. To avoid this aging or minimize its impact, an artificial aging treatment is necessary. The following work was carried out to clarify at what magnesium level will no aging appear and what the resulting mechanical properties are. Tab. 3 shows the chemical analysis of the tested material. Magnesium was added in the range of 0,003 up to 0,1%. The manganese content was kept at the optimum level of 0,6% and the strontium content of 120 ppm which provides a good modification of the eutectic silicon. A test sample with dimension of 220 mm x 60 mm x 3 mm was cast to determine mechanical properties. The test plate was cast in a single cavity die. Again, a 400 t die-casting machine was used with an adapted forced venting system. The melt was degassed by using spinning nozzle techniques and the quality was checked with the low-pressure test. Before degassing density index was observed to be between 3% and 5%. After treatment a density index was less than 2%. No dependency between magnesium content and resulting density indices could be observed. To simulate the long-term aging behaviour

▲
Fig. 7

Yield strength as a function of magnesium content after several heat treatments. Test sample: 220 mm x 60 mm x 3 mm plate.

Carico di snervamento in funzione del contenuto di magnesio dopo trattamento termico. Provini ricavati da piatti: 220 mm x 60 mm x 3 mm.

beside temper F three different heat treatments were used:

- 120 °C for 1000 h
- 130 °C for 3 h
- 180 °C for 3 h

Fig. 7 shows the results of the mechanical properties concerning the yield strength after various heat treatments. Except in the as-cast state, all heat treatments tend to influence the yield strength. The aging starts at a magnesium level between 0,04% and 0,08%. A limit could be estimated to be less than 0,06% magnesium. Concerning the ultimate tensile strength, there was no marked influence. The same could be observed with the elongation. With all conditions the elongation was in a range from 10% to 12%, which is quite high for an aluminium-silicon alloy in the as-cast state.

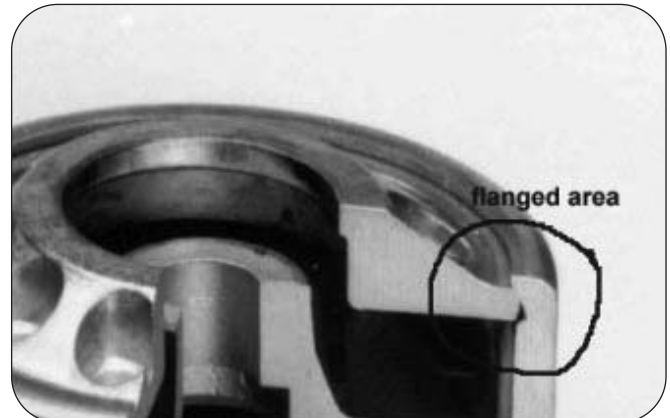
APPLICATIONS

For the magnesium contents around 0,15% a damping part is shown in Fig. 8. The edge is flanged and had to withstand all the forces during lifetime of the part. In the flanged area there must be a sound casting structure. Oxide skins or presolidifications will lead to poor results during the deformation process.

Another interesting application is the seat frame of the new YAMAHA YZF-R6 motorcycle shown in Fig. 9. This is the first street motorcycle ever to use YAMAHA'S new Controlled Filling Die Casting Technique resulting in a lighter aluminium chassis that is stiffer. It is produced with a Magnesium content of 0,2% and has a T5 heat treatment to shift the yield strength above 200 MPa.

SUMMARY

There was an open question concerning ejection behaviour and manganese content in low iron die-casting alloys. Raising iron content to improve ejection behaviour makes no sense, because it will enhance sludge formation in aluminium-silicon alloys [4].

▲
Fig. 8

Damping part showing flanged area, magnesium content 0,15%. Temper F. Courtesy BRT/Fasa, Italy.

Parte di ammortizzatore con flangia, contenuto di Mg dello 0,15%. Stato grezzo. Per concessione di BRT/Fasa, Italia.

▲
Fig. 9

Seat frame, YAMAHA YZF-R6, gives more stiffness and saves weight. Courtesy YAMAHA, Japan.

Parte del sedile, YAMAHA YZF-R6, più resistenza e risparmio di peso. Per concessione di YAMAHA, Giappone.

As it is well known, iron will form needle-like intermetallics in the microstructure and which will have a detrimental effect on the ductility of the cast part. For this reason it is obvious to add only manganese (which forms only compact intermetallics) to the alloy and keep the iron as low as possible.

The tests have shown that the optimum amount of manganese is in the range of 0,5% to 0,8%. In this range elongation stays quite stable as well as the yield strength. Higher manganese content will lead to a decrease of elongation especially when the part is heat-treated.

The second set of trials dealt with the question of what magnesium level is needed to avoid long-term aging. The idea is to have an alloy available that needs no heat treatment for stabilization. Because of the high solidification rate in high-pressure die-casting, more magnesium can go into solid solution compared to permanent mould castings and the aging process can occur at a lower magnesium content.

The results show that at a level of lower than 0,04% magnesium long term aging can be avoided. In addition, a high elongation of more than 10% was measured in the

test parts. This material performance will open opportunities for applications where energy-absorbing properties are required. This will also save costs because no heat treatment is needed.

REFERENCES

1] Koch H., Hielscher U., Sternau H.; Franke A. J., "Silafont™-36, the new low-iron high-pressure die-casting alloy", TMS, Light Metals 1995, 1011-1018

2] Schneider W., Vogel W., Baldering H. "Wärmebehandlung von Aluminium-Gußlegierungen für Druck-und Kokillenguß", GIESSEREI 77, 1990, 693-699

3] Koch H., Franke A. J., "Duktile Aluminium - Druckguss Werkstoffe im Automobilbau", 15 Fachtagung, Prozesskette Karosseriebau, Feb. 2003, Fellbach, Germany

4] Jorstad J. L., "Understanding Sludge", Die Casting Engineer, Nov/Dec 1986

ABSTRACT

SILAFONT-36, UNA LEGA DUTTILE DA PRESSOCOLATA A BASSO TENORE DI FERRO. SVILUPPI E APPLICAZIONI

Parole chiave: pressocolata, alluminio e leghe, trattamenti termici, caratterizzazione materiali

La forza trainante per lo sviluppo e la produzione di nuove leghe da pressocolata arriva principalmente dal settore automobilistico.

Tra il 1990 ed il 2000 il contenuto di alluminio nelle auto passeggeri costruite nell'ovest Europa è cresciuto da 50 a 100 kg per auto. Questo significa una crescita del consumo medio annuo di 5 kg per veicolo, cioè circa il 7%. Nel 2001, il 76 % delle parti colate in alluminio sono state prodotte per l'industria automobilistica. Ben il 70% di queste vengono realizzate in pressocolata.

Lo sviluppo di leghe da pressocolata a basso contenuto di ferro inizia nel 1992 e a dieci anni di distanza si parlava già di 25.000mt di pezzi realizzati con tali leghe. Silafont®-36 (AlSi9MgMn) è stata la prima applicazione con successo di tali leghe da pressocolata per il settore automobilistico.

Il principale obiettivo del presente studio è illustrare i risultati dei tests al variare del contenuto di ferro, dal momento che questo forma nella microstruttura degli intermetallici a forma di ago particolarmente dannosi per la duttilità.

Elementi chiave nella composizione, accanto al silicio e allo stronzio per la modifica sono:

- manganese, che serve per evitare attaccature allo stampo e forma fasi intermetalliche che incrementano la duttilità;

- magnesio, che determina il carico di snervamento e di rottura della lega. In questo studio si è valutato l'effetto dell'aggiunta di manganese, fissandone il livello di aggiunta, per ottenere buona duttilità e comportamento all'estrazione. Anche le proprietà meccaniche in funzione del tenore di magnesio sono riportate, per poi concentrarsi a contenuti tra 0,13-0,35% per controllare il comportamento di invecchiamento a lungo termine.

Nel gruppo delle leghe a basso contenuto di ferro, Silafont-36 di Aluminium Rheinfelden si distingue per facilità di impiego nella fonderia, buona colabilità, buone proprietà meccaniche e caratteristiche di saldabilità. Alcuni esempi di applicazione verranno presi in considerazione per dimostrare le caratteristiche della lega.