# Aluminum Alloys for Structural Die Casting

**Martin Hartlieb**
*Viami International Inc.*
*Beaconsfield, Quebec, Canada*

## Introduction

The number of projects and applications for structural die casting using special alloys and sophisticated process technologies (that are needed to meet the very high requirements on properties of such complex die castings) are increasing exponentially. These structural die castings are often large and thin walled (Figure 1), have to be heat treatable, are welded or joined by self-piercing rivets, need high impact as well as fatigue strength, and need to be very corrosion resistant. Typical die casting alloys rely on high iron (Fe) to beat or overcome die soldering. This (together with certain process deficiencies leading to sometimes significant porosity, inclusions, etc.) prevents traditional die casting alloys from achieving high mechanical properties, especially elongation. In the 1990s in Germany, Rheinfelden developed the first low Fe structural die casting alloy (Silafont™ 36, AA 365). They lowered the Fe to 0.15% max and replaced it with manganese (Mn) at 0.5-0.8% for die soldering resistance. Alcoa developed similar alloys (C601 and C611), but only used them in their own die casting facility in Germany. Others such as Alusuisse/Alcan (Aural™ alloys) and Pechiney (Calypso™ alloys) developed and commercialized similar alloys with up to around 0.2% Fe and around 0.5% Mn. They claim the slightly higher Fe did not do any harm to the properties at the high freezing rate of die casting but that the slightly lower Mn was advantageous for the properties. In Japan the ADC3SF (also known from Ryobi as W3 alloy) uses

*Figure 1 – BMW X5 Shock tower cast by Albany Chicago in Aural-2 alloy.*

even lower (0.3-0.4%) Mn and special part design to overcome die soldering issues. Over a decade later, Mercury Marine discovered that strontium (Sr) was also an element that increases die soldering resistance of die casting alloys and applied this in their Mercalloy™ series of die casting alloys (AA 367, 368, and 362), which therefore allowed them lowering the Mn content even further (to only about 0.3%). Today, these two elements are used to replace the Fe in structural die casting alloys for die soldering resistance thus reducing the very negative impacts of Fe needles (Figure 2) on ductility and feeding behavior, both extremely critical for structural die casting alloys.

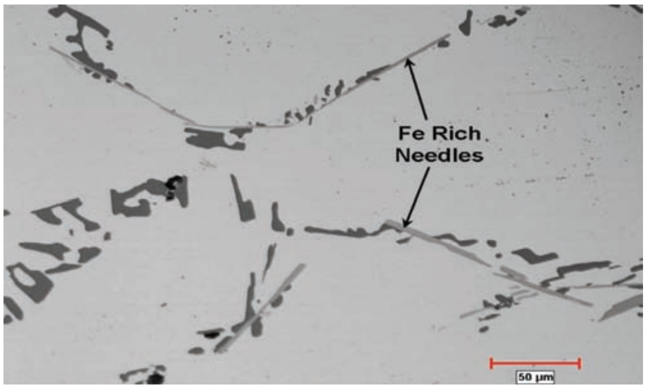


*Figure 2 – $Al_5FeSi$ needle-like phase.*

### What Are Structural Die Castings?

When we talk about structural die castings we typically think of components of the car body structure, such as shock towers, A or B pillars, cross members, engine cradles, or inner door panels. (Figure 3) But we can find structural die castings also in other sectors like marine applications, motorcycle or recreational vehicle frames. What they all have in common is that they are usually quite large and thin walled (often only 2-3 mm thick), and very complex as they integrate several components (previously often stamped sheet parts welded together). This way the complex die castings (which certainly don't compare to traditional die castings in terms of price per pound) could be justified both because of the weight saving and typically also because of the overall cost saving. As these castings are often crash relevant and/or are riveted with self-piercing rivets they require high mechanical properties, especially elongation. They are sometimes welded and/or heat treated which causes porosity to expand and form blisters. This is why any porosity as well as any other defects have to be minimized. Besides special alloys, there


***Figure 3** – Al Space Frame showing structural die castings in red.*

are also very high requirements on the process technologies throughout the entire process chain. From proper melting, melt treatment and transfer, an optimized and properly controlled die casting process (typically applying high vacuum throughout most or all of the shot), often followed by low distortion heat treatment, machining, straightening and surface treatments, all steps need to satisfy highest standards of quality and precision. Quality controls need to be implemented after every step and part traceability and documentation are absolutely vital.

## Alloys For Structural Die Casting

Alloys for the described complex structural components typically require very good fluidity and castability, low Fe and other impurities to obtain high mechanical properties and corrosion resistance, and an optimized chemistry for the component. We distinguish primarily between 2 main alloy families:

The Al with 6-12%Si alloys with up to 0.7%Mg, like Rheinfelden's Silafont™ -36 or Castasil™ -37, Magna BDW's Aural™ -2/-3/-5, Alcoa's C601/611, Mercury Marine's Mercalloy™ 367, 368, and 362, etc.

The Al with 4-6% Mg and up to 3% Si, like Rheinfelden's Magsimal™ -59, Alcoa's C446, Pechiney's Calypso™ 43 and 54SM, etc.

The Al-Si-Mg alloy family is far more popular - especially in North America. The Al-Mg(-Si) family is significantly more aggressive to the dies and more difficult to cast, but offers attractive properties without (solution) heat treatment.

The Si in Al-Si die casting alloys is typically between 7.5 and 12% depending on the required fluidity (higher for increased Si) for a given part. Lower Si will provide higher as cast ductility. Mg imparts strength and hardness, especially if either T5 or T6 heat treated. The $Mg_2Si$-based precipitation hardening displays a useful solubility limit of approximately 0.7% Mg (above this value no further strengthening occurs but matrix softening takes place). It is found that higher Mg in Al-Si type alloys increases the required amount of Mn to beat or overcome die soldering. Mn helps reduce die soldering and also corrects the Fe phase by transforming the β-Fe needles ($FeSiAl_5$) into so-called Chinese script (α-Fe, $(Fe,Mn)_3Si_2Al_{15}$). One problem with Mn additions is the sludge formation at lower temperatures. The sludge factor is defined as SF = (1 x wt% Fe) + (2 x wt% Mn) + (3 x wt% Cr). It needs to be < 1.4 to avoid sludge in a holding furnace at 620 °C (1150 °F) and < 2.0 to avoid sludge at 660 °C (1230 °F). The 380 alloy [2% Fe; 0.5 Mn; SF=3] has a typical microstructure full of sludge particles, while the structural alloys like Silafont-36 [0.15 Fe, 0.80 Mn; i.e. SF=1.75], the Aural-2 [0.2 Fe, 0.5 Mn; i.e. SF=1.2] and Mercalloy 367 & 368 [0.25 Fe, 0.35 Mn; SF=0.95] are designed to avoid or minimize this. Ti is used as grain refiner. Impurities, especially Cu, need to be limited to get best corrosion resistance. Some structural die casting alloys limit copper to only 0.03%, others allow 0.25%, depending on the requirements which typically are determined in a salt spray test (or similar corrosion test with a drying cycle) performed on the specific bare or painted casting.

Sr (0.01-0.02%) helps modify the eutectic silicon, thereby improving ductility of the alloy. It is also found to help beat or overcome die soldering especially at higher levels (0.05-0.07%). Higher levels of Sr are associated with porosity in thick section parts and processes with slow solidification rates, but not in die castings where an intensification pressure is applied. It is said to disperse porosity from macro to micro porosity.

## The Questionnaire and Interviews

More than 150 people participated in the NADCA online survey. In addition, a few dozen personal interviews were also conducted with people (experts) in the industry already in the business or very familiar with structural die casting and the corresponding alloys. The focus was mainly on North American die casters and OEMs but a few key people in Europe were also interviewed as this market is already far more developed for these types of parts and alloys.

In the online questionnaire, people were asked if they were aware of special alloys for structural applications and if they had received requests for structural die castings. About two thirds of the online respondents were aware that die castings with special alloys can be used for structural (including crash relevant) parts, while 43% actually had requests for some sort of structural die castings. About the same fraction answered that they are aware of the effect of Fe on die soldering resistance of the alloy while 51% said they knew Fe reduces mechanical properties, especially elongation. About the same fraction of people were aware that Mn also helps prevent die soldering, but less than 40% were aware of the effect of Mn on changing the Fe needles into so-called "Chinese script." More than two thirds of the respondents answered they know of Sr but only one third knew that it is used to modify the Si eutectic to increase the ductility of the alloy and less than 30% were aware that Sr also helps increase die soldering resistance.

In the personal interviews, an objective was to determine how well people knew why traditional alloys cannot be used for structural applications and most responses were basically correct. What most respondents answered was that the "purity" (particularly with respect to Fe) is very important, and that it requires basically a primary alloy with low trace elements for such applications. All interviewed industry experts knew about the effect of Mn in changing the needle-like morphology of the iron phase and of Sr on eutectic Si modification. Most had heard of the use of Sr for die soldering resistance in the Mercalloy™ alloys. Few people questioned the effect of Sr on die soldering resistance but some had either difficulty with early theoretical explanation of why Sr helps prevent die soldering (initially it was published that it might be due to increase in surface tension – a rather controversial statement that was later withdrawn) or mentioned concerns about possible negative effects of Sr (like rapid fading, overmodification, excessive oxidation, H pickup, reduced feeding/fluidity, and formation of $Al_4SrSi_2$ intermetalics).

It was interesting to see that Mercalloy™ is the best known structural die casting alloy (with over 35% of the online and all of the interviewed people) saying they know the alloy (or have at least heard of it). This is more than the Silafont™ -36 alloy (where 31% of the online respondents knew of it) which has been in the market the longest time and is considered the most popular structural die casting alloy in Europe. It is also used in several programs in North America and Asia. Magsimal™ -59 ranked #3 in terms of brand recognition among the online respondents with 20%, although it is scarcely used in North America (unlike in Europe). Aural™ -2/3 ranked 4th with only 17.5%, although it is currently used in several North American programs by several die casters and OEMs. The Japanese ADC3SF (best known as Ryobi's W3) alloy was only recognized by 8.5% of the respondents, not very surprising as it is mainly used in Japan and by Japanese companies such as Ryobi in North America. Most of the personally interviewed experts knew all of the alloys, but Magsimal™ -59 mainly from literature and W3 / ADC3SF only to a very small extent.

The responses looked quite different when the question was changed to ranking the different alloy brands in order of preference in specifying a structural die casting. Of those who answered this question (69 skipped it), over 50% answered Silafont™ -36 would be their first choice, and over 45% named Aural™ -2/3 their second choice, while Mercalloy™ was only the 3rd choice (almost 40%). In the personal interviews it became very clear that Aural™ -2/3 was not as well known and some people thought to have rather limited availability (and only in combination with a specific die casting technology) – both are rather misconceptions as the alloy itself is easily available and is not linked to any process. The reason for Mercalloy not ranking higher as the alloy of preference was the fact that it was considered either mainly a secondary alloy (which was not considered appropriate enough for structural die castings in terms of purity) or thought to be only for marine applications. Both were also misconceptions as the Mercalloy™ alloys can be made as primary or secondary alloys – simply depending on the needs for a specific part or application, and are available and designed for any use. It just happens to be mainly used for marine applications right now, as they were developed by Mercury Marine – initially for their own use but are now licensed to several alloy producers for general use in any market. The Magsimal™ -59 alloy was not well known and its image was that it is more difficult to cast and has very reduced die life.

When asked about the price and value of the mentioned structural alloys most of the respondents checked "don't know" (80-94% depending on the alloy), and most of those who expressed an opinion checked "reasonable price/value". The interviewed experts almost all stated that the price of the alloy is of course higher than standard alloys (especially A380), but this is by far not the biggest (cost) problem when dealing with these type of castings. The entire process chain needs to be adjusted and optimized to achieve the needed properties, and often additional steps like heat treatment and straightening are required. If for example through an optimized alloy these additional costs (like heat treatment) can be minimized, then this can very well over-compensate higher alloy costs.

The question about how important availability of a given alloy in different regions (worldwide) is was overwhelmingly answered with either very important (46.6%) or important (36.3%). Mainly smaller regional players as well as some OEMs and die casters who prefer using their own or a generic alloy answered that this is not important for them. Silafont™ -36 is available in North America through Noranda, in Asia through Dubal, in Europe it is produced of course by Rheinfelden themselves. Aural™ -2/3 are not patented chemistries in North America although the brand name is protected. It is produced mainly by Rio Tinto Alcan but in Europe also by other alloy producers. Mercalloy™ is produced in North America by Mercury Marine themselves as well as Beck Aluminum and Custom Alloy Light Metals. It can be licensed worldwide from Mercury Marine and they are in discussions with alloy producers in Europe and Asia. Several OEMs mentioned that a much bigger problem than global availability of the alloy is finding capable die casters (for such structural die castings) in all the regions.

We found that 43% of the online respondents had already received requests for structural die castings. Those who answered the question (98 online and all interviewed experts) on how the alloy was specified on the drawing/RFQ answered predominantly with mechanical properties (64.3%). Some have received requests stating (also) either the brand name (30.6%), the European alloy designation (26.5%) or a detailed chemistry (30.6%). Most people agreed that just specifying the desired properties seems to be the most useful way and therefore to leave the final alloy choice to the die caster.

In terms of which properties of the alloy are needed or desired from alloy suppliers (or the die caster proposing it) almost 80% named mechanical (tensile) properties, 56% said they should be taken from representative castings rather than separately cast tensile bars. 49% said they need a true stress-strain curve/diagram (so they can do non-linear analysis). Around 60% answered they would also like to have fatigue and impact resistance data, and 63% answered they would want corrosion data as well.

When asked whether crash worthiness (in a high strain rate loading impact) should be measured solely by the tensile properties (especially ductility) as measured in the tensile machine at low strain rates over 70% answered "no". At least some sort of 3 dimensional bending tests, if not true crush test were considered much more meaningful. Very few said that for Al the speed has much less impact than on other materials.

Technical assistance from the alloy producer was considered very important (51%) or important (31%) by most respondents. Those either very familiar with the alloys or even developing them on their own answered they did not require it, and die casters already using a certain alloy don't necessarily want to add other variants similar to it, especially not for smaller volumes.

In terms of alloy data, 29% of the online respondents answered they would trust the data when it was generated by the alloy producer, while 46% would prefer independent data and 25% would use external data only as a reference because they would produce their own data anyway. The interviewed experts mostly answered that reputable alloy developers and producers like Rheinfelden or Mercury Marine could not risk their image by publishing wrong data, so they would consider them trustworthy; but most would produce their own data in parallel anyway.

## Conclusion

Structural die casting is a market that has been growing tremendously in Europe and to some extent in Japan over the past 20 years, but which is now also growing significantly in North America and represents a great opportunity for innovative die casters. We see a growing number of shock towers, engine cradles, cross members, torque-boxes, and other body structure parts mainly for the automotive but also for other industries. All have in common the desire or objective that they can replace several components (often steel stampings welded together) by one usually large, thin walled and complex die casting with high requirements on mechanical properties. The process requirements for producing such parts are extreme and special alloys (and often heat treatment) are required to achieve the required properties. Several alloys for such die castings have been developed mainly in Europe (and to some extent in Japan and in North America). They can be distinguished into two families: The first is the Al-Si-Mg type alloys with prominent examples like Silafont™ -36, Aural™ -2/3/5, Mercalloy™ 367/368/362, etc. It is more common than the second, the Al-Mg(-Si) type alloys like Magsimal™ -59. The general industry knowledge about these alloys is still rather limited in North America and only very few parts are currently in production using these alloys, but several OEMs are pushing hard to get a supply base for structural die castings established and a few die casters have adopted the necessary technologies or are in the process of doing so. It can therefore be expected that structural die casting will grow and become a significant market in the die casting sector in North America in the coming years.