Structural Casting Alloys with Highest Recycling Content and Lowest Carbon Footprint

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ABSTRACT

With the electrification of vehicles, less powertrain castings and more structural castings are needed. Powertrain castings were mainly produced from secondary alloys, made from post-consumer scrap. Structural castings have been almost completely made from primary alloys to guarantee the high purity and consistency needed for those safety critical castings. Today, not only post-consumer scrap, but also an increasing amount of pre-consumer/industrial aluminum scrap is coming to the market and needs to find new applications. Know-how in terms of scrap recycling, segregation and sorting, as well as melt treatment/cleaning practices have been improving significantly. This allows metalcasters to produce structural casting alloys with high recycling content and therefore low carbon footprint, without negatively impacting their quality and performance. This paper describes the latest trends and developments on this topic and which alloys can be made with which carbon footprint, which types of scrap, and what are the limiting factors.

Keywords: structural castings, die casting, mega-castings, giga-castings, structural casting alloys, recycling content, carbon footprint.

INTRODUCTION

Structural castings have traditionally been made from primary alloys, mainly A356 for Low Pressure Permanent Mold (LPPM) Castings or 365 for High Pressure Die Castings (HPDCs). The metal quality (and achievable properties) depends on the alloy composition (and its impurities) and its cleanliness (inclusions). Making an alloy from primary aluminum and adding the individual alloy ingredients has been considered the easiest and safest way to produce high quality alloy ingots for structural, safety critical castings. Many structural castings such as subframes, cross members, longitudinal members, and many other chassis and suspension castings have been made from A356, typically in T6 temper. The first structural HPDCs in the 1990s for the Audi A8 were made of 365 (AlSi10MnMg / Silafont 36™) alloy, subsequently the A365 (Aural-2™) was introduced in 2000 for the Audi A2 body structure die castings. In the late 1990s AlSi5Mg2Mn (Magsimal-59™) was introduced in Europe but did not find many applications in North America. Today, so-called Mega- or Giga-castings are predominantly made in HPDC on machines with locking forces of 6,000 to 12,000 tons as they can economically produce castings with high integrity and thinner walls than LPPM. With the trend of increasing casting size, the desire to avoid heat treatment (especially solution) has led to the development of AlSi7MnMg type alloys (Aural-5™, Castasil-37™, EZ-Cast™/C611, etc.) for HPDC. They are similar to A356 but with Mn and slightly higher Fe content. Several other alloy types and families as well as enhanced versions of the existing ones have also been developed but do not have any large commercial applications yet.[1] The big challenge of leaving the Al-Si-Mg or Al-Mg-Si family of alloys is recycling content and recyclability, as it is less compatible with other existing scrap streams. For many structural A356 (type) castings, especially recycled wheels are used as a source of high-quality post-consumer scrap to lower their carbon footprint, but the Fe content is often the limiting factor for recycling content. In HPDC, with the much faster freezing of the melt in the die, higher Fe contents can be tolerated.

The car body structures (and closures) today are made with an increasing aluminum content, but so far most of this is stamped sheet metal, which is often made with over 75% recycling content. With the legislative and societal push for increased sustainability – and particularly reduced carbon footprint and increased recycling content – automotive OEMs need structural castings that replace sheet metal, to equally have a high recycling content and low carbon footprint. For this reason, a lot of work has been put into achieving the same quality structural alloys and castings but now with increased recycling content and lowest possible carbon footprint. Without high (post-consumer) recycling content, OEM carbon footprint targets are simply not achievable, and many OEMs directly dictate a certain (often specifically post-consumer) scrap content in their aluminum castings. Foundries are increasingly forced to trace and disclose recycling content and certify the carbon footprint of their castings.

RECYCLING CONTENT AND CARBON FOOTPRINT

It is well known that primary aluminum has a very high carbon footprint, typically from around 4 t CO_2e/t Al ("low-carbon primary" produced with renewable energy) up to around 20 t CO_2e/t Al (when the electricity was produced in a coal-fired power plant), with a global average around 16.7 t CO_2e/t Al (per the International Aluminum Institute – IAI). Scrap or recycled aluminum has a much lower carbon footprint, as recycling is said to only require about 5% of the energy needed to produce primary aluminum and is often published with 0.5 t CO_2e/t Al carbon footprint. This can be misleading as not all scrap or recycled aluminum has the same carbon footprint. Any post-consumer scrap is reset to zero carbon footprint at the scrap yard, as the alternative would (assumed to) be landfill, which is avoided. The carbon footprint of in-process or industrial scrap however can be calculated according to two different methods, which both lead to the same result if the entire life cycle is considered—but will give a different result if not: The "cut-off method" considers the scrap generated during a manufacturing process as CO_2 emission-free and the entire carbon footprint is allocated to the product. The "co-product method" allocates the carbon footprint equally to the material that ends up in a product as well as to all industrial scrap generated during its production. If the scrap generated during the manufacturing process is immediately recycled into the next product, the result is the same. If the scrap is sold to a 3rd party, this can become a significant traceability problem. Some suggest therefore to always consider scrap with zero carbon footprint unless a precise and reliable number can be obtained for a certain scrap. This can easily lead to greenwashing and actually discourages traceability in scrap streams, which is why in such cases it would be better to use industry average carbon footprint numbers.[2] If the by-product method is used then even an alloy made from almost 100% scrap will likely end up with a carbon footprint of at least around 1 t CO_2e/t Al (Figure 1). The A356.2 made from primary aluminum and alloying elements would therefore have a carbon footprint of around 4 t CO_2e/t Al in the best case to over 20 t CO_2e/t Al.

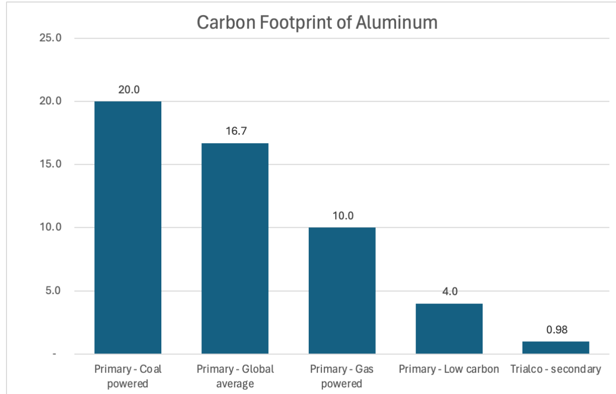

Figure 1. Comparison of different primary and secondary aluminum types (in t CO_2e / t Al). *Data from the International Aluminum Institute (IAI), the Aluminum Association, and internal company calculations.

RECYCLING CONTENT IN STRUCTURAL ALLOYS

The desire and drive to produce structural die casting alloys from scrap, or at least with a very high recycling content, is not new and in fact has been done in the industry for over a decade. Mercury Marine introduced their Mercalloy™ series (362/367/368) as an alternative to the (back then solely primary) 365 and A365 alloys and achieved very similar properties with very high recycling content (mainly from clean crushed wheels). The castings were produced in HPDC, which allows higher Fe contents compared to PM or sand casting, due to the much higher freezing rate in the steel die. Extensive testing was performed with respect to the impact of impurities like Cu on corrosion.[3]

In former times making an alloy from the highest possible recycling content was mainly driven by economics (scrap is usually cheaper than primary metal and alloying ingredients), but today it is becoming a must for achieving carbon footprint targets for castings. Most automotive OEMs have been struggling with recycling content in their specifications of structural casting alloys as the chemistries were defined when these alloys were made only from primary metal and recycled content was considered "unsuitable" (and was therefore often specifically limited in their specifications). Today, most of the common structural die casting alloys can be made with high recycling contents and OEMs are adjusting their alloy specifications for it. While scrap wheels remain the easiest source (with zero carbon footprint when originating from car wreckers) for making almost any of the Al-Si-Mg type structural alloys, this scrap source has a limited volume available in the market and a relatively high price compared to other scrap types. It is therefore important to also find alternative sources of scrap suitable for the typical structural alloys.

RECYCLING CONTENT AND ITS IMPACT

When making an alloy from primary aluminum and (often high purity) alloying ingredients it is easy to achieve chemistry with each element being within a very tight tolerance and with very low impurity levels. Scrap, however, is very diverse – even if one scrap type of (mostly) a single alloy is used. It is also possible to have parts of different alloys, with a certain coating (containing different elements), or foreign objects mixed into the scrap. Alloying elements in one alloy can be impurities in other alloys. Even if using a clean scrap like automotive wheels (in North America are typically made from the A356 alloy – with a tight specification and very low impurities), it is possible to find pieces of wheels made from other alloys, Cu and Ni containing coating (from chrome wheels), Zn from wheel weights or Fe from bolts or valve stems that remain. Recycling dirtier scrap can cause more problems from surface coatings or dirt on the surface, which leads to emissions during melting (captured in the baghouse of the secondary casthouse) and can bring impurities and inclusions into the melt that need to be removed though proper melt treatment like filtering, degassing, fluxing and chlorinating.[4]

Structural die casting alloys are ideal for higher recycling content as the rapid freezing during the HPDC process makes the alloy much more tolerant to higher Fe content than slow-freezing processes like PM or sand casting. The Fe content in Al-Si-Mg or Al-Mg-Si type alloys causes the formation of a brittle β-Al_5FeSi phase (iron “needles”) which negatively impacts the ductility of aluminum castings. Normally in sand casting it is important to keep the Fe level at very low levels (often below 0.08%) to achieve good ductility. In permanent mold this limit is typically 0.15%, and in die casting–in order to achieve the same ductility level–up to 0.25% (or more) is tolerable. To minimize die soldering, Mn is added, which has a secondary beneficial effect when higher Fe is present as it helps suppress the formation of this β-Al_5FeSi phase and instead forming α-$Al_{15}(Fe,Mn)_3Si_2$ phase (so-called “Chinese script”) with rounded or hexagonal morphology, much less harmful to ductility. Sometimes only a fine needle-like π-$Al_8FeMg_3Si_2$ phase in the eutectic is formed. With proper Sr modification and grain refinement, very high ductility can be achieved even in F and T5 temper. Solution heat treatment (T6 or T7 state) can help dissolve the π-$Al_8FeMg_3Si_2$, defragment the typical α-$Al_{15}(Fe,Mn)_3Si_2$ phase and spheroidize the Si phase.[5] Unfortunately most OEMs will try to avoid this as it can cause blister problems in HPDCs and distortion issues. For this reason, several R&D projects are working on chemically achieving the same results and even converting harmful brittle phases into more harmless or even useful alloy constituents.

STRUCTURAL DIE CASTING ALLOYS WITH RECYCLING CONTENT

SCRAP TYPES USABLE FOR MAKING STRUCTURAL CASTING ALLOYS

Not all types of scrap are usable to produce relatively high purity structural die casting alloys. Any alloy (scrap) can be recycled back into the same alloy (if not contaminated during the manufacturing process), but–as mentioned before–certain alloying elements of one alloy can be intolerable impurities in other alloys. Most alloying additions (elements) are irreversible, i.e., they cannot be removed with current technologies in any economically viable way. For example, A380 scrap contains too many alloying elements and impurities to be recycled into any structural alloy (cast or wrought). Due to their typically high Si content, casting scrap is difficult to recycle into wrought alloys, which is why there is very little competition for casting scrap from secondary wrought alloy (billet, slab) casthouses (other than occasional clean wheel scrap as Si addition when the Si price is much higher than the Al price). Many of the wrought alloys of the 6000 series however can be recycled into structural Al-Si-Mg casting alloys and some 5000 series scrap can be used as a source of Mg. When recycling industrial (pre-consumer) scrap, i.e., from a stamping facility, it is more likely to get only one alloy (family) scrap, and if it is mixed, the scrap pieces are at least not joined together. This type of scrap will disappear in the future as most OEMs and their sheet metal suppliers are working on closed-loop recycling concepts that will recycle those alloys directly back into the same alloy. We will, however, see more and more post-consumer scrap from cars made with higher aluminum content (like the Ford F150). Those are, however, welded together and therefore more difficult (or sometimes impossible) to separate. Such mixed 5000 and 6000 series scrap mixes can ideally be recycled into structural Al-Mg-Si type alloys.

The most common extrusion alloys that can be found in typical scrap streams would be 6005A, 6060, 6061, 6063, 6082 and to a lesser degree, alloy 6110. The most common sheet scrap in the 6000 series contains 6013, 6014, 6022 (exterior & structural panels), 6016 and 6111 (exterior panels). The most common 5000 series are 5052 (trucks sidings), 5754 (structure panels), 5182 (inner panels). In small amounts the 5018, 5051A and 5454 can be found. Forgings are typically made from 6061 (most common in North America) or 6082 (most common in Europe). The 6000 series have typically a lower carbon footprint than 5000 series alloys as Mg has a much higher carbon footprint than Al and Si, it can be over 30 t CO_2e/t Mg (while both primary Al and Si are typically between 4 and 20 t CO_2e/t metal).

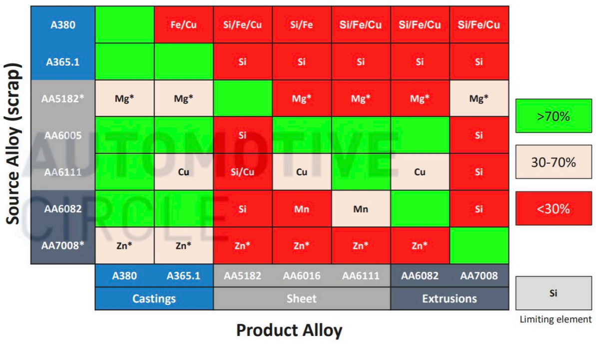

Figure 2. Cross-recyclability of different common alloys in car bodies.[6]

LIMITING FACTORS OF RECYCLING CONTENT IN STRUCTURAL ALLOYS

The most well-known impurity in any structural alloy is Fe, and it is therefore often used as the reference element for whether an alloy can be made with recycling content or not. It is, however, not the only element that can limit the amount of recycled material tolerable in an alloy. Most scrap types available (even if the original part was made from mainly primary metal, like auto wheels) will have an Fe content of over 0.12%, so limiting Fe to 0.12% truly minimizes possible recycling content. However, even an 0.15% Fe limit in the ingot will allow the production of this alloy with very high recycled content (i.e., wheels). Opening the Fe limit to 0.20 or even 0.25% will make it possible to produce the alloy from almost 100% recycling content. The elements making an alloy more prone to corrosion (Cu, Ni, Zn) are also often limited. A limit of 0.02 or 0.03% of those elements can limit the possible recycling content, but already 0.05% will make it easier, and at a 0.1% maximum the alloy can be made from very high (and diverse) recycling content. An element often overlooked as a limiting factor for scrap usage is Ti. Most aluminum scrap contains Ti as it was used for grain refinement in most aluminum components. Limiting this element to 0.10% or below will make it hard to integrate scrap. This is probably one of the elements that received such a low limit in a time when structural alloys were made from primary metal only, as technically it is hard to find good arguments to limit it to such a low level for structural die casting alloys. By putting it to a 0.15% maximum it is no longer a limiting factor for recycling content.

CURRENT TYPICAL STRUCTURAL DIE CASTING ALLOYS AND POSSIBLE RECYCLING CONTENT

Table 1 shows a few of the most common structural die casting alloys in use today and how they can be made in an economically viable way from a mix of primary aluminum, alloying ingredients, pre- and post-consumer scrap. The assumption are current scrap streams/types and their availability and economics, as well as current state-of the art casthouse technology, especially scrap sorting/treatment and melt treatment/cleaning technologies. The A356 alloy for structural LPPM castings would be very similar to the 365 alloy (with a slightly lower alloying element addition), but the assumed post-consumer recycling content (in this case clean scrap wheels) will heavily depend on the required Fe content, but this could be compensated with the use of higher purity primary aluminum.

Table 1. Some Common Structural Die Casting Alloys with Typical Chemistries and Possible Recycling Content (Pre- And Post-Consumer)*

	365.1	A365.1	AlSi7MnMg	AlMg5Si2Mn
Si	9.5-11.5	9.5-11.5	6.5-9.5	1.8-2.6
Fe	0.12	0.15-0.20	0.13-0.2	0.2
Cu	0.03	0.02	0.03	0.05
Mn	0.50-0.8	0.30-0.6	0.3-0.6	0.5-0.8
Mg	0.1-0.5	0.15-0.6	0.1-0.6	5.0-6.0
Zn	0.07	0.03	0.03	0.07
Ti	0.04-0.15	0.1	0.15	0.2
Sr	0.01-0.018	0.01-0.018	0.01-0.018	
Be				0.004
Primary Aluminum	60%	0%	0%	25%
Alloying ingredients	8%	3%	1%	2%
Pre-consumer scrap	0%	0%	0%	33%
Post-consumer scrap	32%	97%	99%	40%

** Source: Author's internal company structural alloy specifications.*

- The main difference between the 365.1 and A365.1 alloy is the Fe content, which is 0.12% for the 365.1 and the Mn content, which is lower in the A365.1 alloy. Even though the A365.1 has a lower Cu and Zn limit, the higher Fe limit allows a significantly higher use of scrap (especially post-consumer scrap) and completely eliminates the need for primary aluminum.
- The AlSi7MnMg alloy has a lower Si content (scrap wheels at 7% are the ideal starting material) and the same Fe and Zn content as the A365.1 alloy. This allows very high pre- and post-consumer scrap content and basically eliminates the need for primary aluminum and alloying ingredients.
- The AlMg5Si2Mn alloy is less common in North America right now but has a very good potential to become the home for the increasing amount of scrap from vehicles like the Ford F150 that contain an inseparable mix of 5000 and 6000 series alloys in the car body and closures. Table 2 shows typical scrap types and chemistries.

Table 2. Typical Scrap Mix of 5000 and 6000 Series Alloys from Car Body Scrap*

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	OE	OT
5182 Segregated	0.20	0.35	0.15	.20-.50	4.0-5.0	0.10	*	0.25	0.10	0.05	0.15
5182	0.20	0.35	0.15	.20-.50	4.0-5.0	0.10	*	0.25	0.10	0.05	0.15
5754	0.40	0.40	0.10	0.50	2.6-3.6	0.30	*	0.20	0.15	0.05	0.15
500/6000 Mixed	1.00	0.25	0.15	0.34	2.00	*	*	0.10	0.05	0.05	0.15

* Typical chemistries as per Aluminum Association and as measured by the author's facility in sheet metal scrap.

With a slight modification of the chemistry (similar to the former Pechiney Calypso 54SM composition) shown in Table 1 it would indeed be possible to very economically produce the alloy from 100% (post-consumer) scrap. Pechiney had developed this narrower range for Mg and Si to optimize feeding ability and reduce hot tear susceptibility. Table 3 shows the suggested composition.

The issue with this alloy family has been:

- *Price*–which could be resolved with recycling content,
- *Castability*–which could be resolved with modified/optimized chemistry and
- *Die Wear*–for which current R&D project seek a solution, i.e., through rheocasting of this alloy.

Table 3. Suggested Optimized Composition for AlMg5Si2Mn Alloy that Could be made from ~100% Scrap

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Na	Ca	Be	OE	OT
Minimum	2.10	0.25	0.00	0.50	5.00	0.00	0.100	0.000	0.000	0.0010	0.000	0.0000
Maximum	2.40	0.40	0.20	0.80	5.40	0.08	0.150	0.0005	0.0005	0.0050	0.03	0.1000
Target	2.20	0.35		0.65	5.20	0.015	0.120	0.000	0.000	0.003	0.000	0.000

ENSURING THE QUALITY OF STRUCTURAL CASTINGS WITH HIGH RECYCLING CONTENT

Structural castings are typically used for safety critical components, and in the case of Mega- or Giga-castings can represent the entire front or rear car body. The quality of the metal impacts both fluidity and castability of the alloy and–more importantly–its mechanical properties and crash behavior. It is therefore vital to ensure that any alloy with recycling content (or entirely made from recycled aluminum) fulfills all the requirements for the critical component it is cast into. To ensure proper metal quality it is important that the ingot producer applies the most stringent rules of scrap sorting and treatment, selects the most adequate scrap types, performs all necessary melt treatment/cleaning steps to remove inclusions and controls the chemistry very tightly. At the die caster it is important (and often required by the customer) to perform melt quality tests to confirm that there is no difference to before (when a primary alloy was used). Therefore, besides the regular spectrometer, Hydrogen (RPT) test, inclusion (K-mold/dross) test, a PoDFA (or PREFIL) analysis needs to be conducted, in which a comparison of the exact inclusion content (by type) is made with the primary alloy and then with the alloy containing recycling content. In addition, in most cases component testing with the castings will also be performed before achieving homologation of the metal with recycling content.

CALCULATING CARBON FOOTPRINT OF STRUCTURAL ALLOYS WITH RECYCLING CONTENT

The most common way of calculating the carbon footprint of a product is according to the Greenhouse Gas Protocol Corporate Standard,[7] which divides all emissions into three Scopes. Scope 1 is direct emissions, Scope 2 is indirect emissions from the purchased electricity, and Scope 3 includes all other emissions including raw materials, logistics, etc. For the production of the above described structural alloys at the author's facility, the following carbon footprint was calculated by ClimatePartner:

Scope 1: (direct emissions)	0.54 t CO_2e / t Al
Scope 2: (indirect emissions from electricity consumption)	0.04 t CO_2e / t Al
Scope 3: (everything else, excluding raw materials)	0,32 t CO_2e / t Al
Total Carbon Footprint: (excluding raw materials)	0.90 t CO_2e / t Al

For the raw materials for each alloy the exact mix for production is taken into consideration. As mentioned before, post-consumer scrap is considered carbon free at the scrap yard (in both cut-off and by-product method), which means that only its transportation to the remelter needs to be considered (part of Scope 3). As for pre-consumer/industrial scrap, either the cut-off method or the by-product method can be applied. To avoid "greenwashing," the by-product method is typically used, which means that either the exact carbon footprint received for the scrap is used for the calculation, or (if not available) the North American average carbon footprint of the respective semi-finished product is used. According to the Aluminum Association Life Cycle Analysis[8] semi-finished extruded aluminum has an average carbon of 6.213 t CO_2e/t Al extrusions (and therefore also for extrusion scrap). For sheet metal this is about 3.978 t CO_2e / Al sheet stamping scrap and for cast scrap this is 1.666 t CO_2e / Al die cast scrap.

Using the cut-off method makes the calculation far easier. In our example structural die casting alloys produced at the Trialco Aluminum facility, the carbon footprint would be as show in Table 4 (broken down into Scope 1 – 3 and raw materials used for each alloy, all scrap used for their production is assumed to be carbon free and only scrap transportation from scrap yards to the author's facility is included in Scope 3):

Table 4. Carbon Footprint of Common Structural Die Casting Alloys Produced With Given Recycling Contents Using Cut-Off Method

Cut-off method	365.1	A365.1	AlSi7MnMg	AlMg5Si2Mn
Scope 1 Trialco	0.54	0.54	0.54	0.54
Scope 2 Trialco	0.04	0.04	0.04	0.04
Scope 3 Trialco*	0.32	0.32	0.32	0.32
Raw materials	3.04	0.24	0.08	1.16
Total carbon footprint t CO2e/t Al	3.94	1.14	0.98	2.06
*) excluding raw materials				

Using the by-product method makes the calculation more complicated for the scrap additions. In our example structural die casting alloys, the carbon footprint would be as follows (assuming industry averages are used for the different types of scrap as no precise carbon footprint for the used scrap was available):

Table 5. Carbon Footprint of Common Structural Die Casting Alloys Produced With Given Recycling Contents Using By-Product Method

by-product method	365.1	A365.1	AlSi7MnMg	AlMg5Si2Mn
Scope 1 Trialco	0.54	0.54	0.54	0.54
Scope 2 Trialco	0.04	0.04	0.04	0.04
Scope 3 Trialco*	0.32	0.32	0.32	0.32
Pre-consumer scrap %	0%	21.0%	2.0%	33.0%
Extrusion	0%	0%	0%	3%
Sheet/Stamping	0%	0%	0.0%	26%
Casting	0%	0%	0.0%	4%
Post-consumer scrap	32%	97.0%	99.0%	40.0%
Raw materials	3.04	0.24	0.08	2.45
Total carbon footprint t CO2e/t Al	3.94	1.14	0.98	3.35
*) excluding raw materials				

It is easy to see that depending on the method used, the carbon footprint is quite different if pre-consumer/industrial scrap is used. If only post-consumer scrap is used, both methods will lead to the same result. The by-product method always means a (slightly) higher carbon footprint if pre-consumer/industrial scrap is used.

For the previously mentioned AlMg5Si2Mn alloy with the suggested chemistry, optimized for high recycling content, it would be possible to produce it from almost all recycled aluminum plus a small amount of alloying ingredients when adjustments are needed, depending on the available scrap types. With an assumed mix of 75% post-consumer and 23% pre-consumer scrap plus 2% alloying ingredients, the carbon footprint would be 1.06 t CO_2e / t Al using the cut-off method, and 1.95 t CO_2e / t Al using the by-product method, a significant reduction to the currently used composition and its carbon footprint.

CONCLUSIONS

Casting applications in vehicles are changing from traditionally mostly powertrain to increasingly structural castings of increasing size (up to Mega-/Giga-castings covering entire front or rear underbodies of light vehicles). While traditionally mostly die castings were used for powertrain applications and most structural/high integrity castings were made in A356-T6 PM/LPPM, today an increasing amount of castings are made in HPDC. Structural aluminum die casting alloys have been around since the 1990s and they have traditionally been made from primary aluminum. With increasing pressure for sustainability and circularity, alloy producers have found ways to make these alloys with certain recycling contents and OEMs have not only accepted this now but are explicitly demanding it. There are different ways of calculating carbon footprint–especially that of (pre-consumer/industrial) recycled aluminum, and it is important to use the right method to avoid greenwashing.

Today, most structural die casting alloys can be made with recycling content, but the amount depends on the exact chemistry and allowed impurity levels. With the right composition (and impurity limits), it is possible to produce a structural die casting alloy with >90% recycling content (mainly post-consumer scrap and sometimes some pre-consumer scrap) with a carbon footprint of sometimes less than 1 t CO_2e/t Al, compared to 4-20 t CO_2e/t Al if it was made from primary aluminum (and alloying elements). Scrap types and streams are changing over time and sorting, and scrap treatment technologies are evolving, so secondary casthouses need to adapt to these changes and constantly implement innovations. Wheels are the ideal input material for Al-Si-Mg type alloys, but they are becoming more and more rare and therefore expensive. Some wrought alloys can also be recycled into casting alloys, and the increasing amount of (end of life) car body and closure scrap (mixed 5000 and 6000 series stampings and some extrusions and/or castings) could find an ideal home in structural Al-Mg-Si type alloys with excellent properties in F temper. Producing structural die casting alloys with high recycling content today is truly possible without compromising casting quality, but only with the right know-how, experience and technologies.

REFERENCES

1. Wiesner, S., Klos, R., Anthony, V., “New Developments in Die Casting Alloys for Structural Castings,” *NADCA Transactions* (2017).
2. Hartlieb, A., Hartlieb, M., Quintero, J., “Trends in Secondary Aluminum Casthouses,” *Light Metal Age* (August 2024).
3. Hartlieb, M., Donahue, R.J., “Mercalloy for Structural Diecasting,” *NADCA Transactions*, (2013).
4. Raabe, D., Ponge, D., Uggowitzer, P.J., Roscher, M., Paolantonio, M., Liu, C., Antrekowitsch, H., Kozeschnik, E., Seidmann, D., Gault, B., De Geuser, F., Deschamps, A., Hutchinson C. , Liu, C., Li, Z., et al., “Making sustainable aluminum by recycling scrap: The science of “dirty” alloys,” *Progress in Materials Science* (July 2022).

5. Cinkilic, E., Moodispaw, M., Zhang, J., Miao, J., "A New Recycled Al-Si-Mg Alloy for Sustainable Structural Die Casting Applications," *Metallurgical and Materials Transactions A*, 53(8), 2861-2873 (May 2022).
6. Rebuffet, O., Payer, T., (Alumobility) "A possibility to reduce the CO2e footprint of the BIW through alloy selection for aluminium-intensive vehicles maximizing circularity," Presentation at: *Car Body Parts: Materials and Forming Processes 2024*, Bad Nauheim (June 11, 2024).
7. "Greenhouse Gas Protocol Corporate Standard," https://ghgprotocol.org/standards-guidance (Link last accessed 03-05-2025.)
8. The Aluminum Association, "The Environmental Footprint of Semi-Fabricated Aluminum Products in North American," A Life Cycle Assessment Report, J. Wang (Jan 2022). https://www.aluminum.org/sites/default/files/2022-01/2022_Semi-Fab_LCA_Report.pdf (Link last accessed 03-05-2025.)