**Light Metals 2015**
*Edited by: Margaret Hyland*
***TMS (The Minerals, Metals & Materials Society), 2015***

# RECYCLING OF AUTOMOTIVE WROUGHT ALLOYS

Ray D. Peterson
Aleris International, Inc., 397 Black Hollow Road, Rockwood, TN 37854 USA

Keywords: Aluminum Alloys, Recycling

## Abstract

More scrap from Automotive Body Sheet (ABS) alloys will soon be entering the North American recycle stream. Some of this scrap will enter from end of life automobiles (post-consumer scrap) while more immediately, scrap will be generated at the automotive stamping plants (post-manufacturing scrap). Current projections show that the recycle rate of post-manufacturing scrap could be of the order of 30,000 tons per year. Unfortunately of the 4 major alloys used in ABS, none are 100 % compatible for use as a feed stock for one of the other ABS alloys. In fact most of the alloys are only moderately compatible with the other ABS alloys. This creates a risk in the recycling of these post-manufacturing materials back into the same alloys if contamination is not closely controlled or dealt with in another manner. Methods to minimize risk from post-manufacturing scrap to the cast house will be discussed.

## Introduction

In 2006 the US Corporate Average Fuel Economy (CAFE) standards[1] were set at 27.3 miles per gallon (mpg) to be achieved by 2011. In 2010 the CAFE standard was then raised to 34.1 mpg for a 2016 target. More recently in July 2011, the Obama Administration raised the CAFE standard target for 2025 to 54.5 mpg. While there are many intricate rules involved in the calculation of the CAFE standard (and it won't be the case where every car has to achieve the 54.5 mpg target), it is fair to say that the fuel economy of all vehicles in North America will have to increase substantially to meet the new target. Consequently large scale usage of wrought aluminum alloys is about to occur in the North American auto industry[2]. Auto manufacturers are turning to increased aluminum usage to reduce the overall weight of autos and thereby increase the fuel efficiency of the automobile.

Figure 1 illustrates historic levels of aluminum shipments to the North American auto industry and shows a prediction of continued increase for the next 4 years[3]. This robust increase in aluminum shipments is driven by two factors: more autos being built and higher levels of usage of aluminum (pounds of Al per car) in the future automobiles. The historical trend for average aluminum content per vehicle and a projection for the next few years are presented in Figure 2. Vehicles like the aluminum intensive Ford F-150 pickup are expected to create this jump in aluminum content per vehicle. Longer term predictions for aluminum usage are even more optimistic.

Since many of the easier cast aluminum parts have already been implemented in automobiles, the growth in aluminum usage will be in auto body panels and closures. Historically the panels have been stamped out of steel blanks. Recently Ford announced[4] that the 2015 Ford F-150 pickup will shed 700 pounds through the use of alternative materials including significant usage of wrought aluminum for body panels. It is estimated that the pick-up will contain over 1000 pounds of aluminum sheet (Body panels and closures are made out of a general class of aluminum alloys termed Automotive Body Sheet [ABS]).

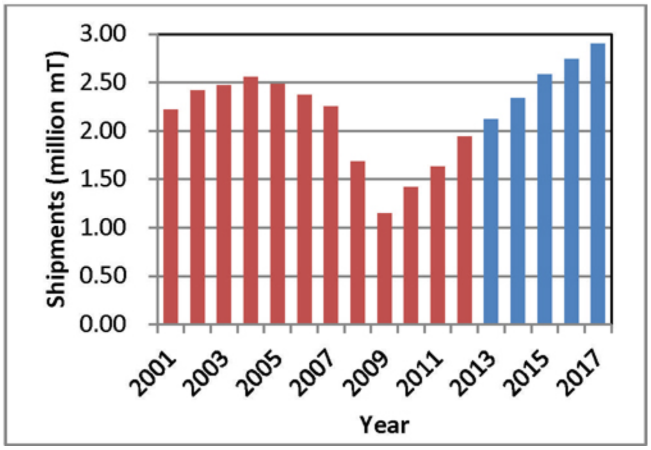


Figure 1. North American Aluminum Shipments to the Auto Market[3].

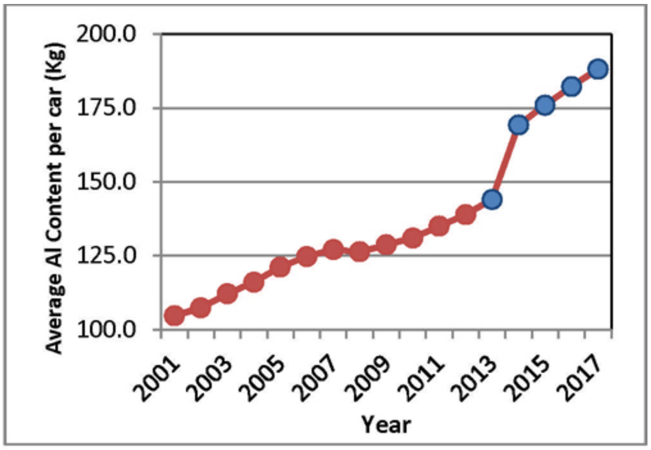


Figure 2. Average Aluminum Content per Automobile in NA Market[2].

Automotive body panels will be produced at stamping plants. It is expected that most of the ABS manufacturers will request that the skeleton scrap from the stamping operation be returned to their system for recycling and reuse. Currently Alcoa, Novelis, Wise, and a Constellium/Tri-Arrows consortium have announced that they will produce ABS alloys. What is unclear at this point is how many different alloys will be used for panels, and if more than one alloy is used at a stamping plant, will the stamping plants and logistics systems be able to maintain alloy segregation when the material is returned to the supplying mill? A recent article in American Metal Market[5] detailed the concerns of the aluminum industry with regard to potentially poor alloy segregation. The article quoted Kevin McKnight saying, "The key ... is to segregate alloys so that they can return back to the highest form of reuse, rather than be 'downgraded,' which is what can happen when alloys are commingled." As will be shown, mixing of scrap types could cause significant issues for the ABS producers.

As a reference point for the impact this new business poses on the aluminum industry, 1.7 billion pounds of new shipments for automotive applications are expected over next four years[3]. If we assume an 85% utilization rate in the stamping process, 64 million pounds per year of new material for recycling will be added to the system.

This paper will focus on the recycling of prompt, or manufacturer automotive wrought alloys, and how the scrap alloys might be utilized. This paper will not address the question of how to handle these and other aluminum alloys that will show up in a few years as these vehicles reach their end of life. Other investigators[6,7] have defined and addressed this problem to varying degrees.

## Discussion

It is generally agreed that 4 main alloys will constitute the bulk of the wrought alloys used in North American car manufacturing. The four alloys are:

| | |
|---|---|
| 5182 | 5754 |
| 6022 | 6111 |

Each alloy has a unique composition as detailed in the top portion of Figure 3. The ranges reported in Figure 3 are the applicable minimum and maximum concentrations as defined in the Aluminum Association's International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys.[8] Actual internal limits for producers of the alloys will likely be tighter than these limits in order to achieve the correct final physical properties required for the final application.

Due to the compositional requirements of these alloys, it is highly likely that they will be primary based. In other words metal produced in aluminum electrolysis cells will be used as the primary source of the aluminum used to produce these alloys. To keep costs low at the stamping plant, the panel producer will want to return the skeleton scrap to an aluminum company for a credit. Returning and reusing this scrap will improve the "recycle content" of the automobile. The aluminum manufacturers want this scrap back as well. In particular, if the alloys can be kept segregated and clean, the panel producer scrap can go directly back into the same alloy at the ABS manufacturer's plant. Having scrap that is already on chemistry reduces the cost requirement for alloying the metal to meet compositional requirements as is the case with prime metal additions.

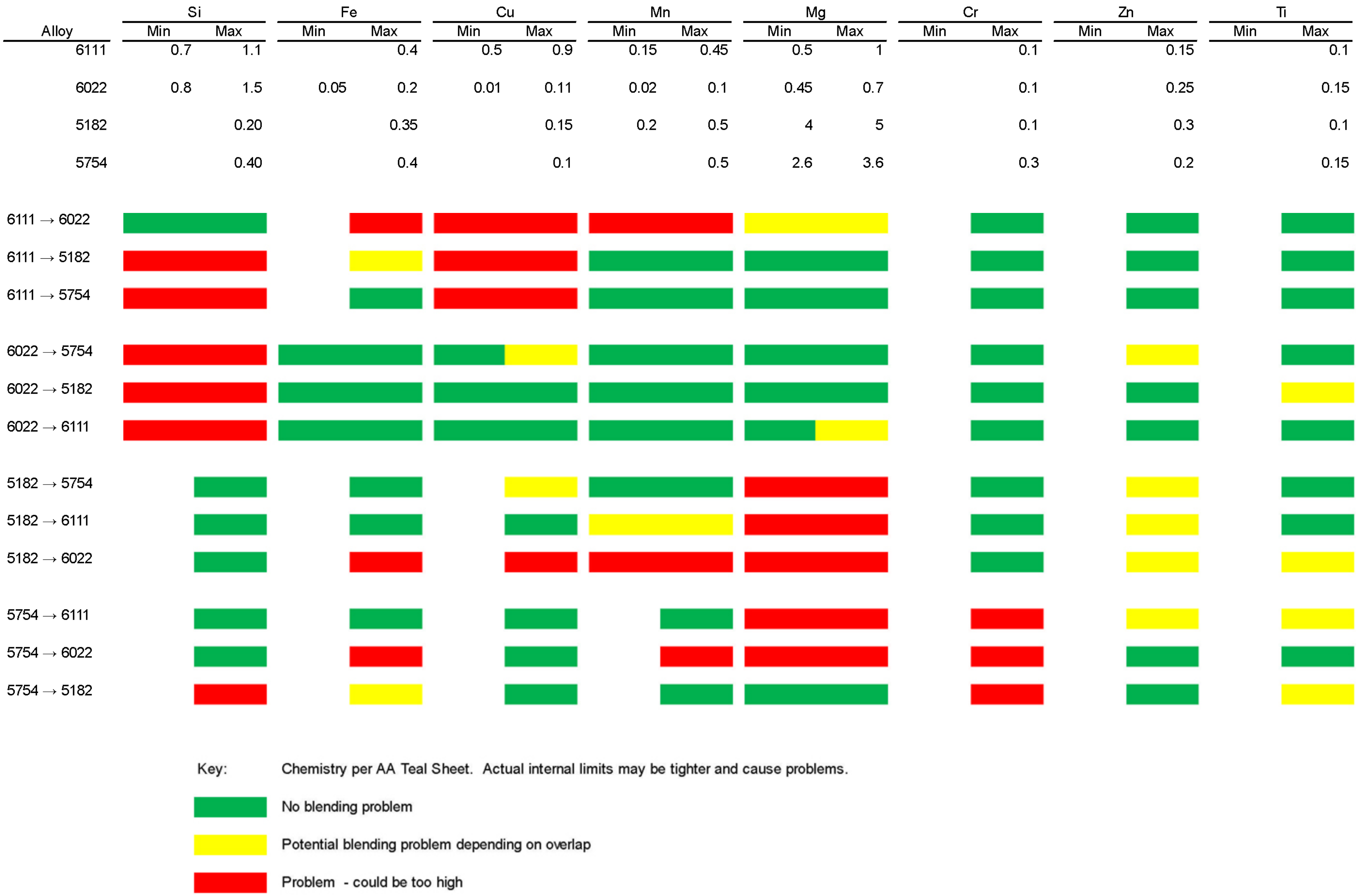
What is more problematic is if the stamping skeleton scrap is to purposely go into an alternative ABS alloy or if the ABS scraps become mixed. In these two cases the entire range of elements has to be reviewed to determine if the alloys are compatible. The compatibility of moving from one ABS alloy into another alloy is visually depicted in the second portion of Table I. Each of the possible combinations of one alloy moving into one of the other three major ABS alloys is depicted. A green block implies that the starting alloy is compatible with the final alloy for this element. Yellow is caution, and red implies the starting alloy is not compatible with the final alloy for this element. As an example, using 6111 as a feed material for making 6022 (the first line in the second portion of the table) is acceptable for silicon (Si) since 6022 has a higher content for Si than 6111; consequently the block is green. The same cannot be said for the element iron (Fe). In this case, 6111 has a higher maximum Fe limit than 6022. If the 6111 alloy was near its upper limit for Fe, it would not be able to go directly into 6022 without dilution; consequently the block is red. Copper (Cu) and manganese (Mn) would have a similar issue for this alloy combination. It should be noted that the composition limits in Table I are from the Aluminum Association. As noted earlier, actual internal composition limits at each supplier are typically tighter than AA limits which could lead to further processing problems. A cursory examination of Table I shows that no direct substitution of one ABS alloy into another is possible.

Since no single ABS alloy can go back into another alloy at a 100 % addition rate, it is critical that all returning alloys be properly identified and segregated. Charging the incorrect scrap to a melting furnace can lead to off-analysis conditions and can become a costly mistake for the melt shop. Another potential problem for the melt shop is having mixed scrap loads with more than one alloy present being returned from the automobile manufacturing operation. This mixed alloy scenario may be the case in the future as these automobiles reach their end of life and the aluminum components are recycled. In Europe automobiles are often disassembled and if the separate pieces were marked, the alloys could be segregated. In the North America, the common practice for End-Of-Life vehicles is to shred the automobile and sort out the mixed aluminum from the other materials. Unless further advanced sorting is performed a mixed alloy scrap is guaranteed.

As has been previously shown, none of the alloys are compatible at a 100 % substitution rate. However, we may choose to use lesser amounts of one alloy as a feedstock for another and make up the balance of the furnace charge with the parent alloy or with a prime based charge. Prime metal can be thought of as a diluent since the relative levels of most of the impurity elements are low in comparison with the final alloy. The typical prime metal used in production of wrought alloys is P1020. The limits[9] for P1020A are given in Table I. In some cases where higher purity requirements are needed or more "dilution power" is required, P0506A can be used. Its compositional limits are also given in Table I.

Table I
Aluminum Association Maximum Chemical Composition Limits for Primary Production Metal

| | | | | Others | |
|---|---|---|---|---|---|
| Designation | % Si | % Fe | % Zn | % Each | % Other |
| P0506A | 0.05 | 0.06 | 0.03 | 0.02 | 0.05 |
| P1020A | 0.10 | 0.20 | 0.03 | 0.03 | 0.10 |



| Alloy | Si Min | Si Max | Fe Min | Fe Max | Cu Min | Cu Max | Mn Min | Mn Max | Mg Min | Mg Max | Cr Min | Cr Max | Zn Min | Zn Max | Ti Min | Ti Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6111 | 0.7 | 1.1 |  | 0.4 | 0.5 | 0.9 | 0.15 | 0.45 | 0.5 | 1 |  | 0.1 |  | 0.15 |  | 0.1 |
| 6022 | 0.8 | 1.5 | 0.05 | 0.2 | 0.01 | 0.11 | 0.02 | 0.1 | 0.45 | 0.7 |  | 0.1 |  | 0.25 |  | 0.15 |
| 5182 |  | 0.20 |  | 0.35 |  | 0.15 | 0.2 | 0.5 | 4 | 5 |  | 0.1 |  | 0.3 |  | 0.1 |
| 5754 |  | 0.40 |  | 0.4 |  | 0.1 |  | 0.5 | 2.6 | 3.6 |  | 0.3 |  | 0.2 |  | 0.15 |
| 6111 → 6022 | 🟩 | 🟩 |  | 🟥 | 🟥 | 🟥 | 🟥 | 🟥 | 🟨 | 🟨 |  | 🟩 |  | 🟩 |  | 🟩 |
| 6111 → 5182 | 🟥 | 🟥 |  | 🟨 | 🟥 | 🟥 | 🟩 | 🟩 | 🟩 | 🟩 |  | 🟩 |  | 🟩 |  | 🟩 |
| 6111 → 5754 | 🟥 | 🟥 |  | 🟩 | 🟥 | 🟥 | 🟩 | 🟩 | 🟩 | 🟩 |  | 🟩 |  | 🟩 |  | 🟩 |
| 6022 → 5754 | 🟥 | 🟥 | 🟩 | 🟩 | 🟩 | 🟨 | 🟩 | 🟩 | 🟩 | 🟩 |  | 🟩 |  | 🟨 |  | 🟩 |
| 6022 → 5182 | 🟥 | 🟥 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 |  | 🟩 |  | 🟩 |  | 🟨 |
| 6022 → 6111 | 🟥 | 🟥 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟨 |  | 🟩 |  | 🟩 |  | 🟩 |
| 5182 → 5754 |  | 🟩 |  | 🟩 |  | 🟨 | 🟩 | 🟩 | 🟥 | 🟥 |  | 🟩 |  | 🟨 |  | 🟩 |
| 5182 → 6111 |  | 🟩 |  | 🟩 |  | 🟩 | 🟨 | 🟨 | 🟥 | 🟥 |  | 🟩 |  | 🟨 |  | 🟩 |
| 5182 → 6022 |  | 🟩 |  | 🟥 |  | 🟥 | 🟥 | 🟥 | 🟥 | 🟥 |  | 🟩 |  | 🟨 |  | 🟨 |
| 5754 → 6111 |  | 🟩 |  | 🟩 |  | 🟩 |  | 🟩 | 🟥 | 🟥 |  | 🟥 |  | 🟨 |  | 🟨 |
| 5754 → 6022 |  | 🟩 |  | 🟥 |  | 🟩 |  | 🟥 | 🟥 | 🟥 |  | 🟥 |  | 🟩 |  | 🟩 |
| 5754 → 5182 |  | 🟥 |  | 🟨 |  | 🟩 |  | 🟩 | 🟩 | 🟩 |  | 🟥 |  | 🟩 |  | 🟨 |

Key: Chemistry per AA Teal Sheet. Actual internal limits may be tighter and cause problems.

🟩 No blending problem

🟨 Potential blending problem depending on overlap

🟥 Problem - could be too high

Figure 3. Automotive Body Sheet Alloy Comparison.

With enough dilution almost any alloy can be used in the production of another alloy. However, at very low addition rates to the furnace, it is not practical to force the "odd" alloy into the other due to handling issues. If we assume that all automotive alloys will be prime based, we can calculate the maximum amount of one alloy that can go into the recipient alloy. Typically it is just one element that causes problems. If the key element is Si or Fe, then using P0506 rather than P1020 may give a slight dilution benefit. Analysis of the additional cost associated with P0506 should be made to ensure that the correct economic decision is made.

Figure 4 presents the breakdown for using one ABS alloy as a source material for production of a second ABS alloy and the amount of the source alloy that could be tolerated with the two different prime metal sources. The figure presents two different cases; for Case 1the normal melting operation is considered while for Case 2 50% magnesium removal by a rotary furnace operation is examined. The figure also shows the limiting element in each case. Let's consider several examples:

- Sourcing 6022 into 6111 – Si is the limiting element for this case. Using P1020 as the diluent, 71.4 % of the total charge can consist of 6022. When using P0506 as the diluent, 72.4 % of the charge is the maximum amount of 6022 that can be tolerated. The additional cost of the P0506 would probably make this a bad choice. Clearly using 6022 as a source scrap for 6111 is readily achievable.
- Sourcing 6022 into 6022 – same alloy so is 100% compatible.
- Sourcing 6022 into 5182 – Once again Si is the limiting element for this case. Using P1020 as the diluent allows only a 7.1% usage of 6022. When using P0506 as the diluent, the usage rate increases to 10.3%. This calculation illustrates that only a small amount of 6022 can be tolerated in the production of 5182. Ensuring little or no contamination of 6022 scrap would be critical when producing 5182.
- Sourcing 6022 into 5754 – Si is the limiting element again for this case. Using P1020 as the diluent allows only a 21.4 % usage of 6022. When using P0506 as the diluent, the usage rate increases to 34.1 %. Using 6022 scrap as feed for production of 5754 is possible but not too convenient. While not as critical as 5182, contamination of 6022 in the scrap could still cause problems.

Figure 4 is color coded to reflect the degree of difficulty in incorporating one alloy into the other. Green implies that 50% or more of the source alloy could be used in the final alloy. This should be a relatively easy and a risk-free task to effectively recycle the returning source alloy into the final alloy. The risk and difficulty increases as the colors progress from green to blue, then pink and finally red. Red blocks indicate 10% or less of the source alloy can be tolerated in the final product. In a few cases it is impossible to use one alloy in the production of another when P1020 is the diluent. 6111 cannot be used as a source alloy for 6022 due to Fe restrictions and 5754 cannot be used as a source alloy for 6022 for the same reason.

In a few cases the limiting element when using one ABS alloy material as the source for production of another alloy is magnesium (Mg). There are three cases where Mg is the limiting element:

| Source | Product |
|---|---|
| 5182 → | 6111 |
| 5182 → | 6022 |
| 5182 → | 5754 |

One attribute of a rotary furnace is that it can be used to preferentially remove magnesium from an aluminum alloy. This phenomenon occurs because the formation of MgO is thermodynamically favored over the formation of $Al_2O_3$. If oxygen is present in the combustion gases Mg will preferentially oxidize over Al. This is not normally a desirable method to operate the furnace since Mg has value, but in this case it might make economic sense.

If we used the rotary furnace operation to reduce the Mg content by 50% in the 5182, it would positively influence the recycle rate of the 5182 alloy as a feed source for the other alloys. The impact of the "demagging" step on maximum addition rate is shown in Table II.

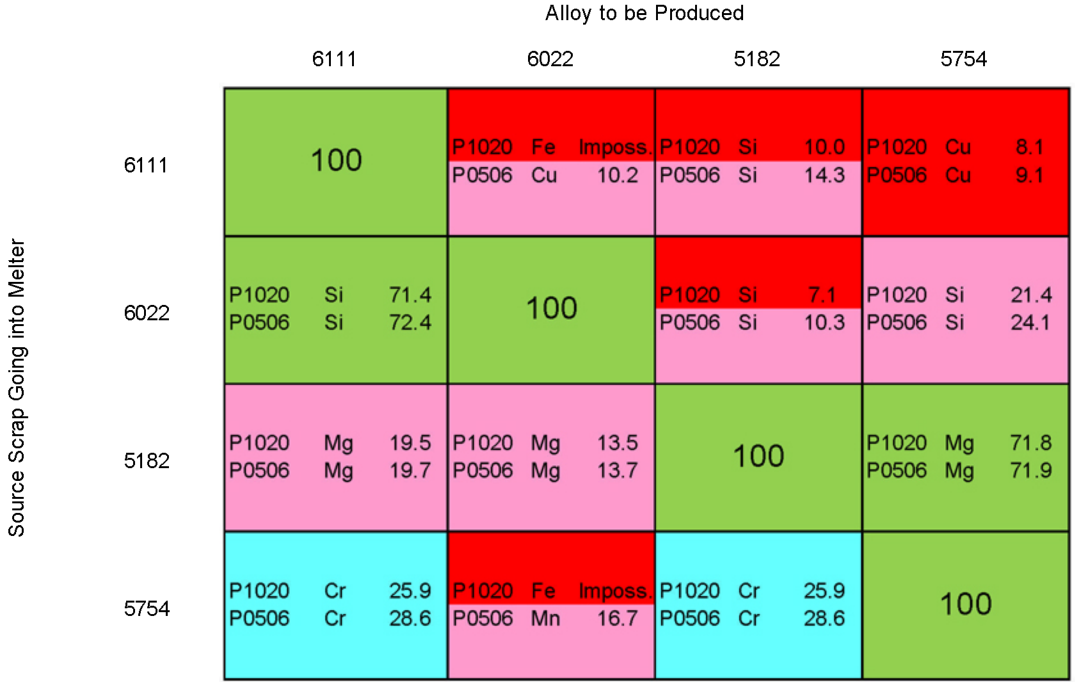
Table II
Impact of Mg Reduction on Incoming 5182 and Its Use as a Feed Material for Other ABS Alloys

| | Without Demagging | | With Demagging | |
|---|---|---|---|---|
| Feed to Product | Max Addition Rate | Limiting Element | Max Addition Rate | Limiting Element |
| 5182 → 6111 | 19.5 | Mg | 39.3 | Mg |
| 5182 → 6022 | 13.5 | Mg | 14.9 | Mn |
| 5182 → 5754 | 71.8 | Mg | 100 | None |

In two of the three cases, lowering the Mg content of the 5182 increases the maximum addition rate of the scrap to make the other ABS alloys. In the case of 5182 as a feed material for 6022, the increase in feed rate is minimal because a new element, Mn, becomes the determining limiting restriction. Using the rotary furnace to remove Mg would not create a benefit in this case.

So what does this all mean for ABS recycling today and in the future? The starting ABS alloy can and should always go back into the original alloy. With proper segregation at the manufacturer, this should be easily achievable. Some, but not all of the automotive scraps can go back into another ABS alloy with proper segregation and proper blending techniques. However, many of the ABS alloys are not compatible to make the other ABS alloys. Consequently knowledge of the scrap received from the stamping facility will be critical for success at the cast shop when making the new rolling ingots. If reliable systems are in place that can keep alloys segregated throughout the manufacturing, collection, transportation and storage processes prior to remelting, then the recyclability of the new ABS scraps will be successful. If any one of these steps in the system fails, then risk of an off-spec furnace dramatically increases along with the potential expense of correcting the problem. With today's melters ranging in capacity from 50 to 150 T and up, the cost of a chemistry mistake can be significant. If the resulting alloy is outside of the internal specification, the furnace will have to be drained and the metal diverted to some other use since the end

**Case 1: Normal Melting Operation**

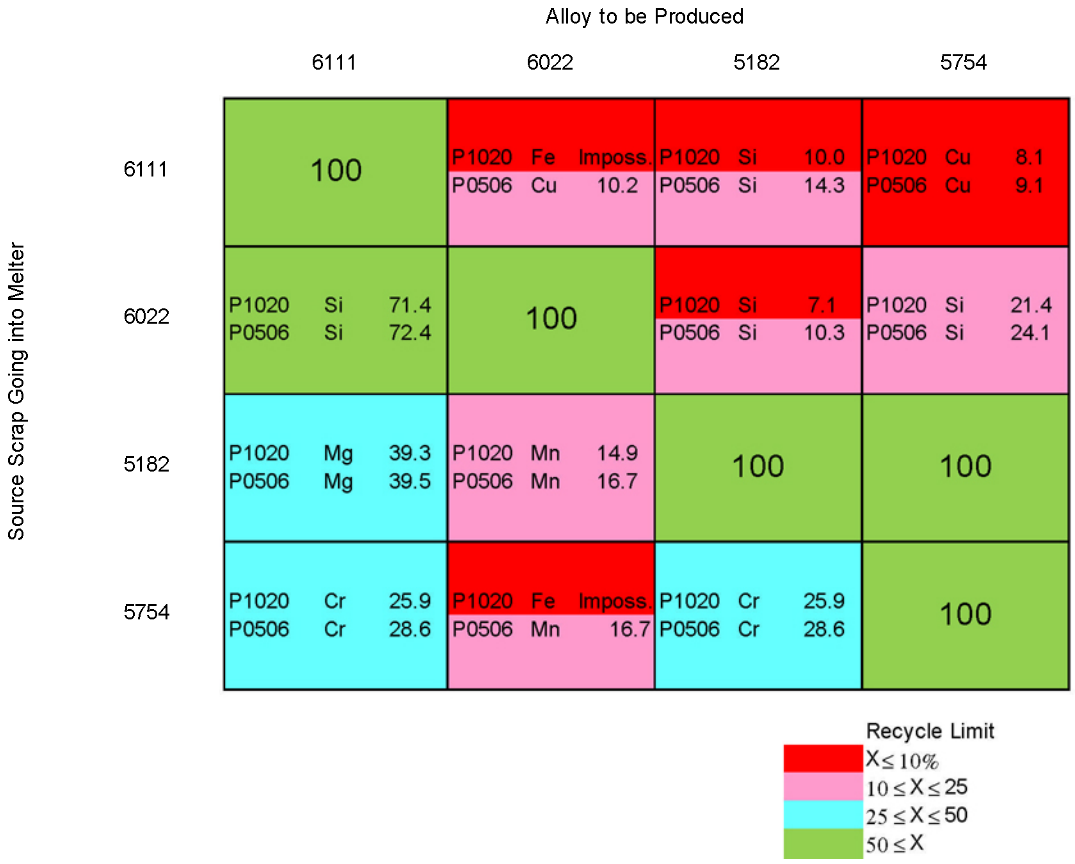


Alloy to be Produced

Source Scrap Going into Melter

| | 6111 | 6022 | 5182 | 5754 |
|---|---|---|---|---|
| 6111 | 100 | P1020 Fe Imposs.<br>P0506 Cu 10.2 | P1020 Si 10.0<br>P0506 Si 14.3 | P1020 Cu 8.1<br>P0506 Cu 9.1 |
| 6022 | P1020 Si 71.4<br>P0506 Si 72.4 | 100 | P1020 Si 7.1<br>P0506 Si 10.3 | P1020 Si 21.4<br>P0506 Si 24.1 |
| 5182 | P1020 Mg 19.5<br>P0506 Mg 19.7 | P1020 Mg 13.5<br>P0506 Mg 13.7 | 100 | P1020 Mg 71.8<br>P0506 Mg 71.9 |
| 5754 | P1020 Cr 25.9<br>P0506 Cr 28.6 | P1020 Fe Imposs.<br>P0506 Mn 16.7 | P1020 Cr 25.9<br>P0506 Cr 28.6 | 100 |

**Case 2: 50% Mg Removal by Rotary Furnace Operation**



Alloy to be Produced

Source Scrap Going into Melter

| | 6111 | 6022 | 5182 | 5754 |
|---|---|---|---|---|
| 6111 | 100 | P1020 Fe Imposs.<br>P0506 Cu 10.2 | P1020 Si 10.0<br>P0506 Si 14.3 | P1020 Cu 8.1<br>P0506 Cu 9.1 |
| 6022 | P1020 Si 71.4<br>P0506 Si 72.4 | 100 | P1020 Si 7.1<br>P0506 Si 10.3 | P1020 Si 21.4<br>P0506 Si 24.1 |
| 5182 | P1020 Mg 39.3<br>P0506 Mg 39.5 | P1020 Mn 14.9<br>P0506 Mn 16.7 | 100 | 100 |
| 5754 | P1020 Cr 25.9<br>P0506 Cr 28.6 | P1020 Fe Imposs.<br>P0506 Mn 16.7 | P1020 Cr 25.9<br>P0506 Cr 28.6 | 100 |

Recycle Limit

| | |
|---|---|
| 🟥 | X ≤ 10% |
| 🟪 | 10 ≤ X ≤ 25 |
| 🟦 | 25 ≤ X ≤ 50 |
| 🟩 | 50 ≤ X |

Figure 4. Alloy Production Compatibility.

product would not be able to meet the customer's final properties. In the case of end-of-life recycling in North America, it is unlikely that the mixed aluminum scrap containing both cast (high Si content) and wrought alloys will be able to be returned to the wrought ABS stream unless sophisticated sorting technology can be applied. Current projections are to divert this mixed Al scrap into the cast alloy stream, but at some point in the future the amount of scrap for this stream may be larger than the demand for those alloys[7].

Luckily there is an alternative to risking the production facility's throughput and costs by processing mislabeled or contaminated ABS scrap from a stamping plant. If the ABS scrap is sent to a rotary furnace operation, the metal can be melted as a single batch unit and the composition can be verified. This methodology has two immediate benefits:

- You can learn about segregation problems in your collection network and give feedback to the various partners in the collection system when a load is discovered to be off-chemistry. If the load chemistry is not on target for the parent alloy, it is possible to calculate the degree of contamination of the desired scrap with that of another scrap.
- Secondly, if the casting facility making the ABS slab ingots knows what the composition of the metal derived from the scrap is before they receive it, the metal planner can manipulate or modify the other feed components so that the off-spec metal can be used. The metal to the casting facility could be in one of two delivered forms: 1.) It could be delivered as molten metal so that its use is almost immediate once the compositional information has been transferred to the producer. Molten metal has many positive aspects for the customer that will not be detailed in this document. 2.) Alternatively, the metal could be shipped in solid form such as Recycled Secondary Ingot (RSI) so that there is plenty of time to make the subsequent processing decisions. In some cases where the contaminated chemistry is too difficult to deal with, the RSI could be sold into other aluminum markets.

Also as mentioned above, if high Mg content alloys need to be used in lower Mg content alloys, the rotary furnace can be used to selectively remove some of the Mg prior to being charged to the melter/holder arrangement at the customer's facility.

## Conclusions

Scrap handling and segregation of ABS alloys will be critical to the success of recycling of these alloys into useful products. As has been shown, the ability to use one ABS alloy when making another ABS alloy is generally limited. Contamination or commingling of alloys becomes a huge deterrent to successfully recycling and returning these materials back to the same product. Segregation throughout the many steps in the collection and recycling process will be necessary.

The longer term issue of mixed aluminum scrap from end-of-life vehicles will need to be resolved. The current process of auto shredding practiced in North America will create a mixed scrap that will most likely need some form of sorting in order to put the scrap into useful subgroups of alloys. Manual removal of aluminum parts as practiced in Europe will address some of this alloying mixing. Unfortunately not all alloys can be segregated by visual inspection so mixed alloys will remain a problem.

Finally utilizing a rotary furnace in the processing of ABS scraps adds many unique opportunities for process improvement. Contamination issues can be addressed earlier in the process with less risk to the slab ingot producer. Use of a rotary furnace to batch melt ABS scrap and provide a known composition for the recovered metal can increase the throughput of the customers casting facility. The rotary furnace can also be used to reduce the Mg level of the final alloy without the use of chlorine. Other process innovations will be needed in the future to handle the new influx of scrap in the near future.

## References

1. CAFÉ- Fuel Economy, NHSTA website, http://www.nhtsa.gov/fuel-economy
2. "2015 North American Light Vehicle Aluminum Content Study," Drucker Worldwide, June, 2014 [Executive summary available at www.alcoa.com/car_truck/en/pdf/2014_Drucker_Executive_Summary.pdf]
3. Private News Letter, "Quarterly Downstream Aluminum Outlook," Lawrence Capital Management, First Quarter, 2014.
4. Many sources such as *Car and Driver* or *Wall Street Journal.*
5. "Aluminum Sheet Faces Scrap Segregation Test," *American Metal Market*, June 16, 2014, pp. 1 and 4.
6. A. Gesing and R. Wolanski, " Assuring the Continued Recycling of Light Metals in End-of-Life Vehicles: A Global Perspective," *JOM*, 52 (11), 21 (2001).
7. R. Modaresi, A. N. Lovik, and D. B. Muller, "Component- and Alloy-Specific Modeling for Evaluating Aluminum Recycling Strategies for Vehicles," *JOM*, published on-line March, 2014.
8. "Registration Record Series Teal Sheets: International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Alloys Aluminum," published by Aluminum Association, Washington DC, February 2009.
9. "Registration Record Series Gold Sheets: International Alloy Designations and Chemical Composition Limits for Unalloyed Aluminum," published by Aluminum Association, Washington DC, March 2007.