CHAPTER 9

Emerging Trends in Aluminum Recycling*

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THE ALUMINUM that goes into the production of aluminum alloy products for many applications comes increasingly from recycled products. In a recent modeling study of the industry, Choate and Green (Ref. 9.1) illustrated that most of the increase comes from recycled automotive components, which, in 2005, was expected to exceed for the first time the recycled metal coming from used beverage cans. The Aluminum Industry Roadmap (Ref. 9.2) also illustrates the importance of these trends and of the efforts to address the technology from primary production to finished products. Fielding (Ref. 9.3) illustrates how one segment of the industry, the extrusion business, is approaching the challenge.

As Choate and Green (Ref. 9.1) demonstrated, the increase in available recycled metal is a positive trend, because secondary metal produced from recycled metal requires only approximately 2.8 kWh/kg of metal produced, while primary aluminum production requires approximately 45 kWh/kg of metal produced. It is to the industry and national advantage to maximize the amount of recycled metal, both from the standpoint of energy savings and reduction of dependence on overseas sources (now approximately 40% of U.S. consumption) and also from the ecological standpoint, because recycling emits only approximately 4% as much CO₂ as primary production.

A joint study of a representative American community by Secat, Inc., the Center for Aluminum Technology, and the Sloan Industry Center for a Sustainable Aluminum Industry found that for each 1% increase in the amount of aluminum cans recycled, the economic savings to the U.S. economy is $12 million/year. This will approach $600 million/yr if all the available aluminum is recycled. The additional recycling also contributes to energy savings of 1 trillion Btu/year. For the United States as a whole, recycling also has the potential to significantly decrease reliance on overseas sources of primary aluminum metal.

Aluminum recycling in North America is one of the well-developed and mature metals recycling economies in the world. While today’s (2007) recycling metals markets also include ferrous metals such as iron and steel and nonferrous metals such as copper and brass, aluminum recycling is the engine of recycling economics. However, it is clear that more should be done to maximize the advantages of a recycling-friendly world. The growth in aluminum usage in transportation applications, the decline in aluminum beverage can recycling, and the increasing reliance of the domestic fabrication industry on secondary aluminum have combined to create new needs in both the materials design and processing realm.

Today (2007), in order to meet the performance requirements of many alloy and product specifications, much of the recycled metal must be “sweetened” with the more costly and energy-intensive primary metal before it can be

re-employed in many applications. The specialty alloys required for a number of applications require such strict controls on impurities that recycled metal cannot be used without modification. The result is that, in many cases (except beverage cans), recycled metal tends to be used primarily for lower-grade casting alloys and products. While a certain amount of this is acceptable, the recycling-friendly world will only be truly optimized when the recycle loop is closer to a closed loop within a number of product lines.

This chapter details the history and future projections for aluminum recycling, emphasizing the increasing importance of mixed-scrap streams in the makeup of secondary aluminum. For the most economical use of these scrap streams, new approaches are needed to develop acceptable materials processed to control properties suitable for an expanded range of applications. This chapter discusses how the aluminum enterprise, including industry, academia, and government, can work together to meet these important but aggressive targets and transform recycling from strictly an environmental imperative to an economic development opportunity.

Objectives and Challenges

A robust recycling regime for aluminum would include:

• Recycled products to approach the total required for new consumption, with less dependence on primary production
• Use of automatic sorting, shredding, and separation technology to facilitate its reuse in new products
• Having a variety of existing and new aluminum alloys with compositions suitable for direct reuse of most recycled metal, so the opportunities for direct use of the recycled, shredded, and sorted metal would be optimized
• Developing a number of high-value applications, such as beverage cans, into which the recycled metal would flow. In such situations, product made directly from the recycled metal would readily meet both specification composition and mechanical property limits of the intended applications.

Among the key challenges to be met in creating this ideal recycling-friendly world are:

• Maximize recovery of used aluminum products and components for recycling
• Identify more useful by-products to handle residual elements; for example, aluminum alloys containing relatively high iron content identified for deoxidizing steel (de-ox)
• Automate and optimize the presorting, shredding, and separation technologies
• Broaden the number of available aluminum alloys whose specifications will readily accept recycled metal and will perform well in high-quality, value-added products

Progress has been and is still being made in addressing the first three challenges. One significant new development in terms of automated sorting is the application of laser-induced breakdown spectroscopy (LIBS) for sorting of aluminum and aluminum alloys (Ref 9.4). An overview of this technology, developed and applied by Huron Valley Steel Corp., is described in Chapter 8, “Identification and Sorting of Wrought Aluminum Alloys” in this book.

The fourth challenge, the identification of new alloys that more readily accept recycled aluminum, has received little attention. However, the potential economic and environmental benefits are sufficiently great for more attention to this challenge. There are a number of detailed challenges facing any effort to increase the number of aluminum alloys and applications suitable for direct production from recycled metal.

The Nature of Recycled Metal

As a starting point in considering the challenges faced in directly using recycled aluminum scrap, it is appropriate to look at representative compositions observed in such metal. Representative compositions of recycled aluminum are shown in Table 9.1 from presorting wrought and cast alloy scrap (Ref 9.4), so two samples were of wrought separations, two of cast separations, and one mixed. These representative compositions illustrate several of the fundamental complications in directly reusing scrap aluminum:

• Even segregated wrought scrap can have relatively widely varying compositions. Wrought lots 3 and 4 in Table 9.1, for example, have higher copper (from more 2xxx alloys) and higher zinc (from more 7xxx alloys) in the mix than did wrought lots 1 and 2. It appears that auto bumper alloys such as
7029 and auto body sheet alloys such as 2036 were more highly represented in wrought lots 3 and 4.

- Some lots of wrought recycled metal (lots 1 and 2) match existing wrought alloys reasonably well, for example, 3005, 3104, 3105, and 6061, and can be readily reused; others, such as lots 3 and 4, will be more difficult to use directly.

- Cast alloy scrap can vary greatly in composition. Cast alloy scrap also differs significantly from wrought alloy scrap, notably with higher total alloy content, higher silicon content, and, depending on which cast alloys are involved, higher copper (from 380.0 and 390.0) and zinc (from 7xx.0 cast alloys).

- Compositions resulting from mixed wrought and cast scrap will be more difficult to use directly because of their combinations of higher silicon, copper, and zinc.

With the exception of recycled beverage cans, most recycled aluminum involves a mixture of alloys from a fairly wide variety of applications, including a selection of castings containing rather high percentages of silicon. While there is generally no problem recycling most of this metal as castings, there is a significant challenge in shredding, sorting, and, in some cases, further refinement of the metal to achieve acceptable impurity levels for products other than castings, including sheet, plate, forgings, and extrusions.

This is particularly true for any of the specialized alloys produced today (2007), for example, those used in the aerospace industry where requirements for exceptionally high ductility and toughness are common. Such performance requirements call for very tight composition controls on both iron and silicon. Impurity levels above 0.15% Fe or 0.25% Si are unacceptable in premium aerospace alloys such as 7050, 7055, and 7475. Similarly, some high-performance automotive alloys (e.g., 5457 and 6111) restrict both silicon and iron to 0.40% maximum. Both of these elements (iron and silicon) are difficult to control in recycled metal and tend to increase modestly the more often the metal has been recycled.

Iron, in particular, can be a significant challenge because of its tendency to increase gradually in metal recycled over and over again, primarily from pickup from scrap-handling system equipment. As a result, iron is an ideal candidate for application to alternative products, an excellent example being the use of high-iron-bearing aluminum as a deoxidizing agent for steel production. It should be noted that elements other than iron may also be expected to increase with repeated recycling and to require special attention, for example, magnesium, nickel, and vanadium.

**Cast Alloy Scrap.** As noted earlier, recycled metal from castings can often be used directly in new cast products, usually of the 3xx.0 and 4xx.0 series, because the impurity limits tend to be relatively high, and almost all contain relatively high silicon, which improves their flow characteristics in the dies. Examples of scrap-tolerant casting alloys are shown in Table 9.2. Even these relatively tolerant limits pose a challenge for direct recycling reuse. For all except 336.0, for which no “Others” limit exists, the “Others” contents noted in scrap samples are higher than desired. In the 4xx.x series, the tight magnesium contents will be a challenge. Nevertheless, casting alloys as a whole have higher impurity limits than wrought alloys and will be more tolerant for direct recycling.

### Table 9.1 Representative compositions of presorted wrought and cast scrap

<table>
<thead>
<tr>
<th>Lot</th>
<th>Al</th>
<th>Cu</th>
<th>Fe</th>
<th>Mg</th>
<th>Mn</th>
<th>Si</th>
<th>Zn</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrought 1</td>
<td>97.1</td>
<td>0.11</td>
<td>0.59</td>
<td>0.82</td>
<td>0.21</td>
<td>0.51</td>
<td>0.45</td>
<td>0.19</td>
</tr>
<tr>
<td>Wrought 2</td>
<td>96.7</td>
<td>0.30</td>
<td>0.60</td>
<td>0.60</td>
<td>0.20</td>
<td>0.90</td>
<td>0.50</td>
<td>0.10</td>
</tr>
<tr>
<td>Wrought 3</td>
<td>93.1</td>
<td>0.95</td>
<td>1.01</td>
<td>0.89</td>
<td>0.12</td>
<td>2.41</td>
<td>2.15</td>
<td>0.27</td>
</tr>
<tr>
<td>Wrought 4</td>
<td>93.1</td>
<td>1.20</td>
<td>0.70</td>
<td>0.70</td>
<td>0.30</td>
<td>2.60</td>
<td>1.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Cast 1</td>
<td>83.5</td>
<td>4.40</td>
<td>1.10</td>
<td>0.40</td>
<td>0.30</td>
<td>8.0</td>
<td>1.90</td>
<td>0.40</td>
</tr>
<tr>
<td>Cast 2</td>
<td>86.0</td>
<td>3.90</td>
<td>1.00</td>
<td>0.10</td>
<td>0.20</td>
<td>6.30</td>
<td>2.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Cast 3</td>
<td>88.4</td>
<td>2.50</td>
<td>0.75</td>
<td>0.58</td>
<td>0.26</td>
<td>5.18</td>
<td>1.27</td>
<td>1.09</td>
</tr>
<tr>
<td>Mixed wrought and cast</td>
<td>90.1</td>
<td>2.30</td>
<td>0.80</td>
<td>0.50</td>
<td>0.20</td>
<td>4.50</td>
<td>1.20</td>
<td>0.30</td>
</tr>
</tbody>
</table>

### Table 9.2 Sample of cast alloy scrap compositions

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Cu</th>
<th>Fe</th>
<th>Mg</th>
<th>Mn</th>
<th>Si</th>
<th>Zn</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>B319.0</td>
<td>3.0–4.0</td>
<td>1.2 max</td>
<td>0.10–0.50</td>
<td>0.8 max</td>
<td>5.5–6.5</td>
<td>1.0 max</td>
<td>0.50 max</td>
</tr>
<tr>
<td>336.0</td>
<td>0.50–1.5</td>
<td>1.2 max</td>
<td>0.70–1.3</td>
<td>0.35 max</td>
<td>11.0–13.0</td>
<td>0.35 max</td>
<td>- -</td>
</tr>
<tr>
<td>C443.0</td>
<td>0.6 max</td>
<td>2.0 max</td>
<td>0.10 max</td>
<td>0.35 max</td>
<td>4.5–6.0</td>
<td>0.50 max</td>
<td>0.25 max</td>
</tr>
</tbody>
</table>
Wrought Alloy Scrap. The extent of the current opportunity as well as the challenge in directly reusing recycled wrought alloy scrap without “sweetening” with primary metal is much greater. This can be illustrated by comparing the compositions in Table 9.2 with those of several wrought commercial alloys already recognized as good consumers of scrap (Table 9.3).

As noted earlier, material from wrought lots 1 and 2 could reasonably be used in alloys such as 3105 and 6061. Even for these alloys, the maximum limit on “Others” may be a challenge, because that value for wrought 1 is slightly in excess of the limit. Scrap from wrought lots 3 and 4 could not be directly reused without flexible impurity limits (see the section “Developing Recycling-Friendly Compositions” in this chapter). Material from the cast lots could not be used directly for any of these wrought alloys or any others, for that matter.

An additional elemental impurity problem needs to be recognized, and that is the general trend for iron content in scrap reused over and over again to increase gradually, primarily through pickup from scrap-handling system equipment. With only a few exceptions, iron is an impurity in wrought alloys today (2007) and is an ideal candidate for application to alternate products (e.g., a deoxidizing agent in steel production). Maximization of this capability will benefit both the aluminum and steel industries and add to the life-cycle benefits of aluminum operations. Another possible approach to the increased iron content is to make use of the affinity of zirconium for iron, resulting in a heavy particle that sinks to the bottom of crucibles during processing. Combining this iron-zirconium product with magnesium and perhaps other undesirable impurities such as nickel and vanadium may also improve their impact on the resulting recycling content.

Recycling Aluminum Aerospace Alloys (Ref 9.5)

As an example, consider the principal challenges for effective recycling of aircraft. For decades, thousands of obsolete aircraft have been sitting in “graveyards,” while the demand for recycled aluminum continues to increase. The discarded aircraft provide a large source of valuable metal. However, cost-effective recycling of aircraft alloys is complex, because aircraft alloys are typically relatively high in alloying elements and contain very low levels of impurities to optimize toughness and other performance characteristics.

Thus, recycling of aluminum aerospace alloys represents a major challenge to both the aluminum and aerospace industries. While the recycling of high percentages of aluminum from packaging and automotive applications has been commercialized and has become economically attractive (Ref 9.1–9.3), the unique compositions and performance requirements of aerospace alloys have resulted in the delay of directly addressing techniques for cost-effectively recycling ignore those alloys. Aluminum remains the most economically attractive material from which to make aircraft and space vehicles, and new construction proceeds at a prodigious rate. However, the development of newer aircraft structures has proceeded at such a pace that thousands of obsolete civil and military aircraft stand idle in “graveyards” around the United States. Yet, it has been impractical to reuse the metal in these planes because of the combination of the differences in compositions of older, obsolete aircraft and those of new aircraft, which often have special performance requirements for specialized alloy compositions.

Cost-effective means is the subject of a study (Ref 9.5) for recycling aluminum alloys used in the production of private, civil, and military aircraft. The principal challenges that must be dealt with in creating this ideal aircraft-recycling scenario include:

- Identifying decision options for dismantling aircraft to simplify recycling
- Identifying and optimizing technologies for automated shredding, sorting, and remelting of those 2xxx and 7xxx alloys with relatively high levels of alloying elements (sometimes in excess of 10%)

| Table 9.3 Sample of wrought alloy scrap compositions |
|-------------|-----|-----|-----|-----|-----|-----|-----|
| Alloy | Cu | Fe | Mg | Mn | Si | Zn | Others |
| 3005 | 0.30 max | 0.7 max | 0.20–0.8 | 1.0–1.5 | 0.6 max | 0.25 max | 0.15 max |
| 3104 | 0.8 max | 0.6 max | 0.8–1.3 | 0.8–1.4 | 0.6 max | 0.25 max | 0.15 max |
| 3105 | 0.30 max | 0.7 max | 0.20–0.8 | 0.30–0.8 | 0.6 max | 0.40 max | 0.15 max |
| 6061 | 0.15–0.40 | 0.7 max | 0.8–1.2 | 0.15 max | 0.40–0.8 | 0.25 max | 0.15 max |
• Identifying the range of representative compositions likely to be obtained from recycling aircraft components, dependent on the amount of presorting that proves practical
• Identifying the combination of performance requirements and compositions that would make useful aircraft components from recycled metal, even though they may not achieve the highest attainable levels of toughness
• Identifying useful by-products to handle elemental residue unable to be used in recycled metal, for example, iron

These challenges include many of the general issues of aluminum recycling. As noted, progress is being made in the application of LIBS for shredding and sorting of some aluminum alloys. In general, however, little or nothing has yet been done to apply recycling technology to shredding, sorting, and reuse of recycled metal from obsolete aircraft and space vehicle components. Implementation issues addressed in Ref 9.5 include:

• Dismantling and presorting strategies
• Automated shredding, sorting, and remelting
• Identifying the resulting compositions of recycled aircraft components
• Options for reuse of the metal from recycled aircraft components in new aircraft
• Options for reuse of the metal from recycled aircraft components in nonaircraft applications
• Options for reuse of the metal from recycled aircraft components in aluminum castings

Of these issues, the latter three options are described as follows.

### Options for Reuse of the Recycled Aircraft Components in Aircraft

Table 9.4 illustrates composition examples from presorting of 2xxx and 7xxx alloys. Assuming that these estimated compositions are reasonably correct, it would appear that the resultant alloys could be used for a number of noncritical aircraft components, such as stiffeners, flaps, and other relatively low-to-moderately stressed components made of sheet, plate, or extrusions. These may be used in private, civil, and many military aircraft. Typically, these would be components that are not designed based on fracture mechanics concepts employing fatigue crack growth rates and fracture toughness parameters. Alloys for fracture-critical areas may still have to be fabricated using primary metal. Further study is needed to estimate the percentage of aircraft components that do not require fracture-critical design and whether it is broad enough to justify the reuse of compositions likely to result from recycling.

### Options for Reuse of the Recycled Aircraft Components in Nonaircraft Applications

If the use of these compositions for non-fracture-critical components in new aircraft is too tightly limited, that is, if the number of non-fracture-critical components in civil and military aircraft is not large enough to justify reuse of the recycled compositions, it is useful to look at the other opportunities that may exist for use of the compositions (Tables 9.5, 9.6).

To aid in addressing that question, the compositions of several wrought 2xxx and 7xxx alloys used in other applications (including 2014, also an aircraft alloy) are presented in Table 9.7. Comparing compositions in Tables 9.5 and 9.7...
illustrates that it may be possible to reuse recycled aircraft metal in certain other products. Further study of this option is justified.

Options for Reuse of the Recycled Aircraft Components in Castings. Other opportunities for the use of recycled metal from aircraft may include aluminum alloy castings, especially those of the 2xx.0 and 7xx.0 series, aluminum-copper and aluminum-zinc, respectively. Examples of such alloys are included in Table 9.8. Even these relatively tolerant limits pose challenges for direct reuse of recycled metal. Nevertheless, opportunity for study of new alloy options remains, and the properties of the alloys in Table 9.5, when produced as casting, should be studied.

Alloys Designed for Recycling

As noted, an ideal component of resource maximization in recycling would be the availability of a larger number of aluminum alloys suitable for a wide variety of applications that do not require any extra purification step before they are recycled into high-performance products. That is largely the case with beverage cans, if the recycle scrap is not mixed with any other material.

Such an approach calls for “tailored” alloys. The goal of identifying new recycling-friendly aluminum alloy compositions is to increase the opportunities to directly, or with only minor modification, reuse recycled scrap aluminum products. Such an approach requires compositions with relatively broad specification limits on major alloying elements, such as copper and magnesium, plus more tolerant (i.e., higher) limits on iron, silicon, and other impurities, without significant restriction on performance characteristics for many applications.

Full development of this approach requires several important steps. Application of LIBS, developed by Huron Valley Steel Corp., to screen scrap with certain combinations of the desired elemental additions may permit relaxation of the broadest interpretation of the aforementioned guidelines, but it is beneficial to look at the most useful long-term trends when such technology may not be available. Adopting the approach of alloy optimization for recycling requires several steps, which are potentially phases in a development program. The phases may include:

- Identify with increasing precision the range of expected current and future recycled metal content, using feedback from organizations that are already capitalizing on the economics of recycling. Perform a mass balance to the extent practical, indicating the relative volumes of various scrap compositions to be expected
- Identify approximately five to seven basic candidate compositions of alloys that would accept recycled metal directly and have acceptable/desirable performance characteristics for a wide variety of applications, including structural components for bridges and buildings, high-temperature applications, and architectural usage
- Evaluate the performance of these candidate alloys in representative production lots, including, in particular, the following, along with the usual tensile and design properties, in order to assess their abilities to meet the requirements of representative applications as compared to existing alloys (Ref 9.6–9.11):
  a. Atmospheric corrosion resistance
  b. Stress-corrosion crack growth

| Table 9.7 | Nominal compositions of some 2xxx and 7xxx alloys used in nonaerospace applications |
|-----------|---------------------------------|---|---|---|---|---|---|---|
| Alloy     | Applications                     | Cu  | Fe  | Mg  | Mn  | Si  | Zn  |
| 2014      | Railroad; truck bodies           | 4.4 | 0.7 max | 0.50 | 0.8 | 0.8 | 0.15 max |
| 2017      | Rivets                          | 4.6 | 0.7 max | 0.60 | 0.7 | 0.5 | 0.25 max |
| 7129      | Auto bumpers                    | 0.7 | 0.3 max | 1.6 | 0.1 max | 0.15 max | 4.7 |

| Table 9.8 | Some aluminum casting alloy compositions |
|-----------|-----------------------------------------|---|---|---|---|---|---|---|---|
| Alloy     | Al | Cu  | Fe  | Mg  | Mn  | Si  | Zn  | Others |
| 2014      | −95 | 4.6 | 0.15 max | 0.35 | 0.35 | 0.10 | 0.25 | 0.05 max |
| 2019      | −94 | 4.1 | 0.6 max | 1.4 | 0.10 max | 0.6 max | 0.10 | 0.05 max |
| 2950      | −94 | 4.5 | 1.0 max | 0.03 | 0.35 max | 1.1 | 0.25 | 0.05 max |
| 7100      | −93 | 0.5 | 0.5 max | 0.7 | 0.05 max | 0.15 max | 6.5 | 0.05 max |
| 7130      | −91 | 0.7 | 1.1 max | 0.35 | 0.6 max | 0.25 | 7.5 | 0.05 max |
c. Toughness, with tear tests and/or fracture toughness tests (for thick sections)
d. Formability tests, with bulge, minimum bend, and hemming tests

It is recognized that there will be some negative effects; the question is the degree to which such alloys are still useful for high-volume applications.

Developing Recycling-Friendly Compositions

Based on what is known about recycled aluminum metal, preliminary candidates for recycling-friendly alloys can be considered. Attention is given here primarily to wrought alloy compositions, because, as noted earlier, casting alloys already can be produced in rather large quantities from recycled cast products. The greatest challenge is direct use of recycled wrought products. The rationale is to define alloy specifications that can be readily met using recycled aluminum with no addition of primary metal. The target applications for the new recycling-friendly aluminum alloys include many of the same as for their existing counterparts, with tighter limits. Examples may include:

- 3xxx: heat-exchanger tubing, chemical piping
- 4xxx: forged or cast engine parts
- 5xxx: tankage plate; housing components
- 6xxx: extruded structural components

While suitable performance requirements with the higher level of impurities may not be entirely successful, steps in that direction will enable the aluminum industry to maximize its recycling opportunities. Therefore, addressing the challenge of a new approach to alloy design is warranted.

Candidate Compositions for Recycling-Friendly Aluminum Alloys. In developing candidate compositions, the following rather basic guidelines have been used:

- For major alloying elements in a particular series (e.g., copper in the 2xxx series, silicon and magnesium in the 6xxx series, etc.), propose relatively broad specification limits. Select alloying elements that are commonly and successfully used in alloys of the various series, for example, 2024 or 2219 in the 2xxx series, or 7005 in the 7xxx series.
- For limits on elements not usually added intentionally or on undesirable impurities (e.g., iron, nickel, and vanadium), propose more tolerant (i.e., higher) limits to the degree potentially practical, to the levels of those elements typically found in recycled metal.

Table 9.9 shows six preliminary candidate wrought alloy compositions that may reasonably be made from recycled and shred-sorted wrought products with, at minimum, the addition of some alloying elements. In this initial list, one composition has been selected from each major alloy series. Other candidates may well be devised by adjustments in the major alloying elements and/or the addition of other minor alloying elements.

These are only preliminary candidates, and it is recognized that the completion of phase 1 (described in the preceding section as identifying to a higher precision the compositions of incoming scrap, current and future) may result in significant changes in these candidate alloys. It may also lead to a focus on several different candidates from specific series that show maximum fit with the incoming metal (e.g., the 3xxx, 5xxx, and 6xxx series representing the highest volumes of recycled metal).

The application targets for these candidate compositions are much the same as their existing counterparts with tighter limits, recognizing that these are not likely to be suitable for the more fracture-critical items. However, the possibility exists that they may perform quite satisfactorily in such applications as chemical plant piping (A-2xxx), heat-exchanger tubing (B-3xxx), forged or cast engine parts (C-4xxx), rolled and extruded structural components

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Zn</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (2xxx)</td>
<td>0.7</td>
<td>0.6</td>
<td>5.5–7.0</td>
<td>0.2–0.4</td>
<td>0.7</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>B (3xxx)</td>
<td>0.7</td>
<td>0.6</td>
<td>0.4</td>
<td>1.0–1.5</td>
<td>0.8–1.5</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>C (4xxx)</td>
<td>10.0–14.0</td>
<td>1.0</td>
<td>0.5–1.5</td>
<td>0.3</td>
<td>0.8–1.5</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>D (5xxx)</td>
<td>0.7</td>
<td>0.6</td>
<td>0.3</td>
<td>0.05–0.35</td>
<td>2.0–3.0</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>E (6xxx)</td>
<td>0.3–1.0</td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4–1.0</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>F (7xxx)</td>
<td>0.5</td>
<td>0.6</td>
<td>0.5–1.2</td>
<td>0.3</td>
<td>2.0–2.8</td>
<td>4.0–6.0</td>
<td>0.3</td>
</tr>
</tbody>
</table>
The application of LIBS technology to screen scrap with certain combinations of the desired elemental additions may permit relaxation of the broadest interpretation of the aforementioned guidelines, but it is beneficial to look at the most useful long-term trends when such technology may not be widely available.

**Unialloy.** Another approach that may be considered, and one that has been studied to considerable degree in the past, is the development of one or two “unialloys,” that is, alloys that meet all the requirements for a large application, such as aluminum beverage packaging, automotive components, or architectural components. The aforementioned approach of selecting “recycle-optimized” alloys from each series may lead to a master list of several recycling-friendly alloys.

The unialloy concept was first developed by Golden Aluminum (Ref 9.12) in the late 1980s and focused on alloy AA5017 with 2% Mg and 0.7% Mn. The concept was derived from the idea that unialloy had an average weighted composition of can body alloy AA3004 and can end alloy AA5182. This recycling idea achieved limited application due to economic and commercial factors. In the current environment of rising prices of primary aluminum and its alloying elements, such as magnesium, manganese, and copper, coupled with the societal desire for enhancing recycling rates of products, it is time to rethink applicability and commercialization of the unialloy concept.

This has proven difficult to achieve because of the diverging performance requirements of different applications. Even within autobody panels, for example, the differing requirements for dent resistance in outer panels and optimized formability for inner panels continue to lead to two different types of alloys being used (for example, 6111 heat treated for high outer panel dent resistance, and 5754 annealed for maximum formability for inner panels).

**Some Caveats.** The large bank of alloy design experience in the aluminum industry may well result in skepticism about the probabilities of success and the seeming backward movement in the aforementioned approach of permitting higher levels of impurities in new alloy candidates. There is indeed some reason for the skepticism, because it is well known that optimizing fracture toughness, for example, requires tight impurity controls, especially on iron and silicon. So, it is probably appropriate to acknowledge at the outset that it may be impossible to reach the stage where recycled metal will be used untreated for all aluminum alloy products, such as fracture-critical-component aerospace wings and wing spars; the fracture toughness requirements on these are simply too stringent to be met without tight impurity controls.

However, aerospace applications account for only approximately 8% of the total approximately 14 to 18 × 10^6 metric tons (30 to 40 billion lb) of aluminum used annually. Therefore, the adoption of a recycling-friendly alloy system applicable to most other applications will still have a very great economic and ecological benefit in world consumption.

The performance requirements of many high-volume aluminum products, such as building and highway structures and chemical industry components, may well be satisfied by alloys with higher levels of impurities than presently mandated. In fact, most composition limits were set when the greater volume of production was primary metal and there was no need for higher impurity levels. The limits were not set by performance requirements but by anticipated incoming metal compositions.

Finally, it must be acknowledged that attempts at obtaining suitable performance requirements with higher levels of impurities may not be successful. However, any step in that direction will better enable the aluminum industry to maximize its recycling opportunities; therefore, the challenge of a new approach to alloy design is warranted.

**Conclusions and Looking Ahead**

There are significant economic and ecological advantages in maximizing the recycling rates of aluminum and the ready reuse of recycled metal. Several important conclusions for the aluminum industry, both in the United States and throughout the world, include:

- **Avenues for recovery of aluminum scrap** from as many products as possible should continue to be exploited; there are massive economic, energy, and ecological advantages to the communities and to the aluminum industry.
- Development and application of enhanced shredding and sorting technologies should continue.
A focus on the most cost-effective remelting processes is justified, including the possibility of combining iron with zirconium and other impurities such as nickel and vanadium in high-density particles that could be easily separated from the melt.

The production of alternative products such as aluminum-iron deoxidizing agents should be pursued to use that part of recycled aluminum products that cannot cost-effectively be used in the production of new aluminum alloys, to the benefit of both the steel and the aluminum industries.

The most overlooked aspect of maximizing recycled metal appears to be the development of new alloys tailored to meet composition and performance criteria when produced directly from recycled metal. A study of the type suggested in the section “Alloys Designed for Recycling” in this chapter should be carried out to potentially add to the number of alloys available for direct recycling. Some candidate compositions have been suggested for such alloys, with the intent to broaden this part of the discussion and perhaps lead to interesting and economically attractive components to maximize recycling efficiency and effectiveness.

Looking ahead, the challenge is to identify the most successful means of implementing the additional studies and development programs needed to maximize the benefits of recycling. Accordingly, one step may be the formation of an aluminum recycling consortium to consider options and opportunities to increase the overall effectiveness and efficiency of aluminum recycling and its benefits. The consortium could include representatives of:

- The municipalities and their representatives at the first line of collecting recycled metal
- The recyclers themselves (e.g., members of the Aluminum Association Recycling Division)
- Fabricators and distributors of recycled products (e.g., auto and beverage can producers)
- End-users of such recycled products

In this regard, Secat, Inc. is in the process of forming an aluminum recycling consortium to further the goals outlined in this chapter. The first two charges of the consortium should be to:

- Identify all means of maximizing the amount of aluminum products entering the recycling chain. Carry out the study of alloy design optimization for recycling as described in the section “Alloys Designed for Recycling,” identifying the most likely high-volume recycling compositions, carrying out the resultant mass balance, and fine-tuning several candidate compositions that would take advantage of the anticipated recycling content
- Explore opportunities to improve the quality of the melt by removal of high-density particles formed by the combination of iron with zirconium and possibly other high-density elements such as nickel and vanadium.

The next logical step would be a complete evaluation of the physical, mechanical, corrosion, and fabricating characteristics of whatever optimized recycling candidate alloys are generated. Successful application of these various approaches to maximizing the cost-effectiveness and efficiency of recycling processes should lead to increased opportunity to extend the life-cycle advantages of aluminum alloys, increase the usefulness of directly recycled alloys, and therefore increase the amount of metal that is directly reused without the addition of primary metal.

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