Light Metals 2011 *Edited by: Stephen J. Lindsay*
TMS (The Minerals, Metals & Materials Society), 2011

QUALITY ASSESMENT OF RECYCLED ALUMINIUM

Derya Dispinar[1], Anne Kvithyld[1] and Arne Nordmark[1]
[1]SINTEF Materials and Chemistry, Trondheim, N-7465, Norway

Keywords: *Recycle, aluminium, metal quality, mechanical properties, remelting, bifilm index*

Abstract

One of the serious problems during remelting of aluminium is the presence of surface oxide including coating. In this work, a wrought and a cast alloy were selected and subjected to remelting experiments. 3000 wrought alloy sheets with three surfaces; (i) before anodising, (ii) between anodising and coating and (iii) after coating, was investigated. The bifilm index was measured as a measure of metal quality; 3-point bending and tensile testing samples were collected for mechanical testing. A good correlation between the mechanical properties and the bifilm index was found. For the surface treated sheet skimming reduces the bifilm index. After skimming the melt in (i), (ii) and (iii) have the same quality, that is a comparable bifilm index and mechanical properties. However, the bifilm index of the cast alloy decreased after remelting three times, thus decreasing the quality.

Introduction

Environmental concerns, particularly increased energy cost and consumption of natural resources have led to production by recycling. It is a well-known fact that recycling requires about 5% of the energy needed for primary production. Today recycled aluminium accounts for one-third of aluminium consumption world-wide. Nevertheless, there is a long going discussion about the quality issues of the secondary aluminium.

One of the problems during remelting of the aluminium scrap is contamination from surfaces as well as the surface oxide of the scrap itself. After the melting process, approximately 10% of the charge is lost due to these oxides and removal of the slag [1-4]. It was also shown [5-7] that turbulent transfer and pouring of the melt increases the metal losses even more. During the melting of the charge in the crucible, the surface oxide of the material may thicken, becoming often micrometres or even millimetres thick [8-12]. Thus, the recycling/remelting of aluminium is not straight forward and simple, it requires extra attention.

Since quality is of central importance for the final product, a series of remelting experiments were carried out in this work. The metal quality change was assessed by a reduced pressure test using the bifilm index [13] and employing mechanical tests.

Experimental procedure

Materials

0.5 mm thickness wrought 3000 coils (Table 1) were collected from different stages in the coil coating production: (i) before anodising (ii) between anodising and coating, (iii) after coating. Premium grade primary ingots of A356 alloy (Table II) were provided by Alcoa Norway.

Melting procedures

6 kg of each coil material was melted at 720°C in an induction furnace. 10 reduced pressure tests samples (Fig 1) were taken for metal quality check (i.e. bifilm index measurement). 10 cylindrical bars were cast for tensile testing (Fig 2) and 10 plates were cast for 3 point-bending tests.

65 kg of premium grade primary ingots were melted in a resistance furnace at 740°C. The melt was poured into plate-molds where the surface to volume ratio was designed to be high (80x20x700mm). All of these plates were then charged into the crucible and remelted in an induction furnace at 740°C. This procedure was repeated 3 times. Sampling was as described above.

Reduced Pressure test (bifilm index)

Molten aluminium is poured into a sand mould with dimensions given in Figure 1, leaving the metal to solidify under vacuum at 100 mbar, which enhances pore formation. Thc bifilm index [13] is the sum of the maximum length of the pores; giving a total oxide length for a given surface area Figure 2. A rule of thumb: is 10 mm; best quality, 10 - 50 mm: good and over 50 mm: bad metal quality.

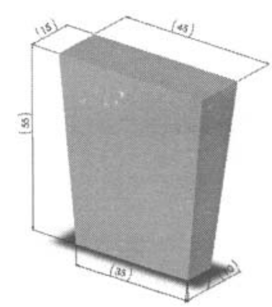


Figure 1. Dimension of sand mould sample for the reduced pressure test

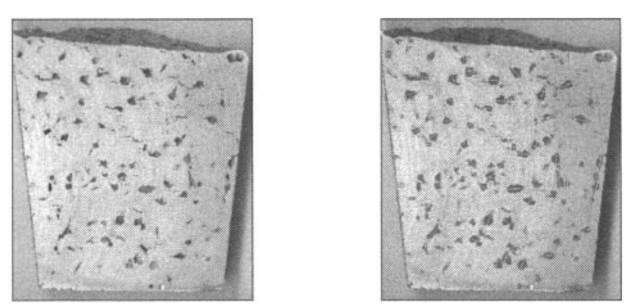


Figure 2. The maximum length of the pores are measured. Added values give the bifilm index.

Table I. The chemical composition of wrought 3000 coils

Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Pb	Ti	Al
0.53	0.58	0.20	0.68	0.34	0.02	0.01	0.23	0.01	0.02	rem.

Table II. Chemical composition of cast alloy A356

Si	Mg	Mn	Fe	Ti	Na	Sr	P	Al
6.9	0.32	0.002	0.116	0.11	0.0012	0.0005	0.0002	rem.

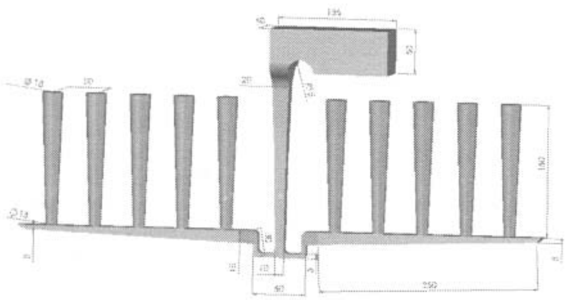


Figure 3. Dimension of the tensile test pattern

The oxide formed over the surface of the coil material was characterized by SEM and TEM

Result

The oxide layer thicknesses analyzed on the surface of the 500 µm coil material are:

(i) Untreated surface:
- 10 nm aluminum oxide layer

(ii) Anodised surface:
- 200 nm aluminum oxide layer

(iii) Coated surface:
- Primer : 2.2–3.0 µm both sides
- Topcoat + 25 µm front side
- Topcoat + 35 µm back side

Recovery

6 kg of 3000 charges ((i) untreated; (ii) anodized; (iii) coated were melted in each experiment, and after the melting, the dross was skimmed off. When the sample collection was complete, the dross and the remaining material were weighed separately, and the melting yield was calculated, shown in Figure 4.

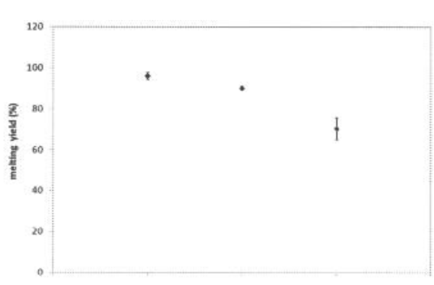


Figure 4: Melting yield of the 3000 coils with different surfaces (i), (ii) and (iii).

Effect of skimming

Ten reduced pressure test samples were collected in each experiment. First two samples were collected before skimming. It was found that the bifilm index was high for the two samples. This indicated a high oxides content for (iii) anodized and coated (Fig 5). After the dross is skimmed off, the melt quality is observed to remain constant for the next four measurements as seen in Figure 5.

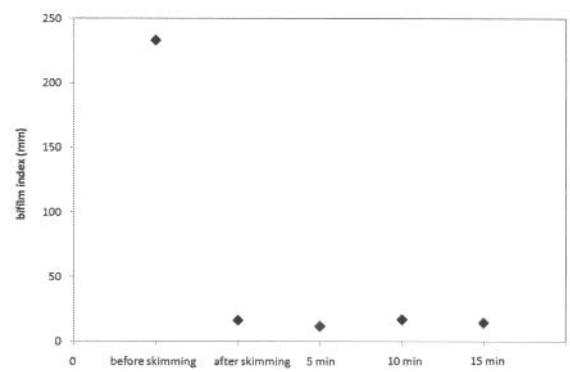


Figure 5: Effect of skimming observed in RPT

Aluminium sheet

The average bifilm index measurements of 3000 coils collected from the different section of the production line are given in Figure 6. As seen in figure, the bifilm index results for (i) 'untreated', (ii)' anodized' and (iii)'anodized + coated' charges have values in the same range of 9 mm, 10 mm and 15 mm respectively.

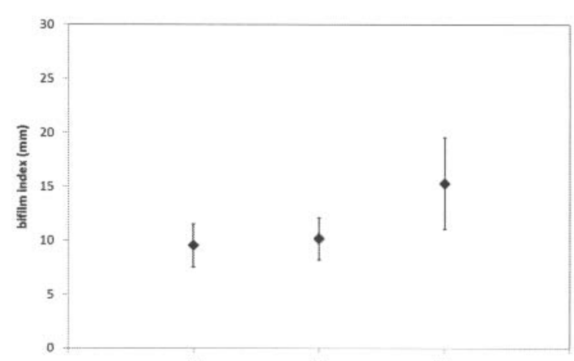


Figure 6: Bifilm index of remelted sheet materials.

Mechanical results for (i), (ii) and (iii) are given in Figure 7. Both the ultimate tensile results (a) and the elongation at fracture (b) values appear to be same within the uncertainty limits. For the max bend strength (c), the (iii) 'anodized + coated' material seems to have a slightly lower value.

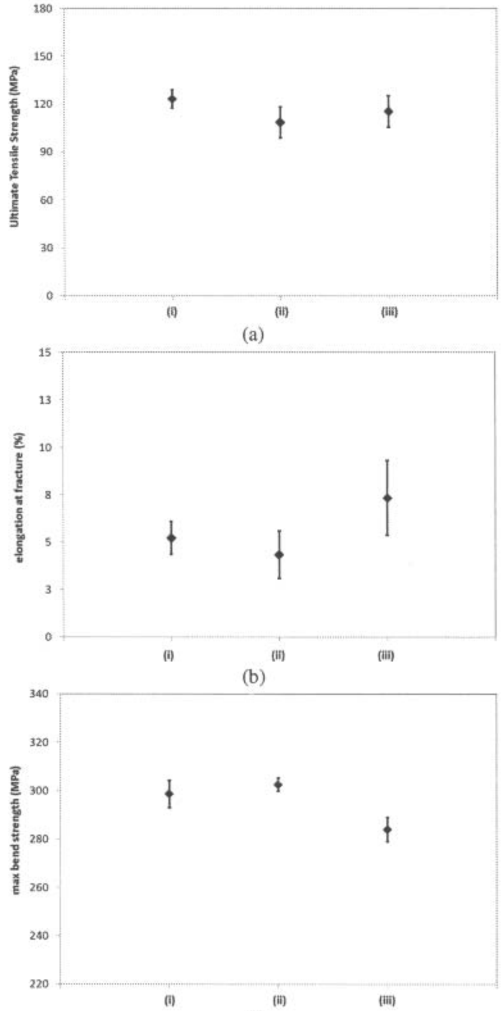


Figure 7: Mechanical test results of the sheet materials (a) ultimate tensile strength, (b) elongation at fracture, (c) 3-point bend test

Ingots

The bifilm index change of the ingot material after three times remelting is given in Figure 8. It was not practical to skim the surface. Premium quality primary A356 had a bifilm index of 13 mm. After three times remelting and pouring into plate shapes with a high surface to volume ratio, the bifilm index significantly increased to 110 mm. A similar result was found with the mechanical tests (Fig 9). The ultimate tensile strength was 166 MPa and it dropped down to 150 MPa; with elongation at fracture dropping from 2.7% to 1.9%. Max bending strength was also decreased from 345 MPa to 319 MPa.

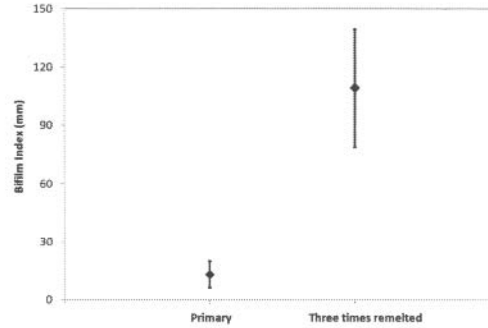


Figure 8: Bifilm index change remelted of A356

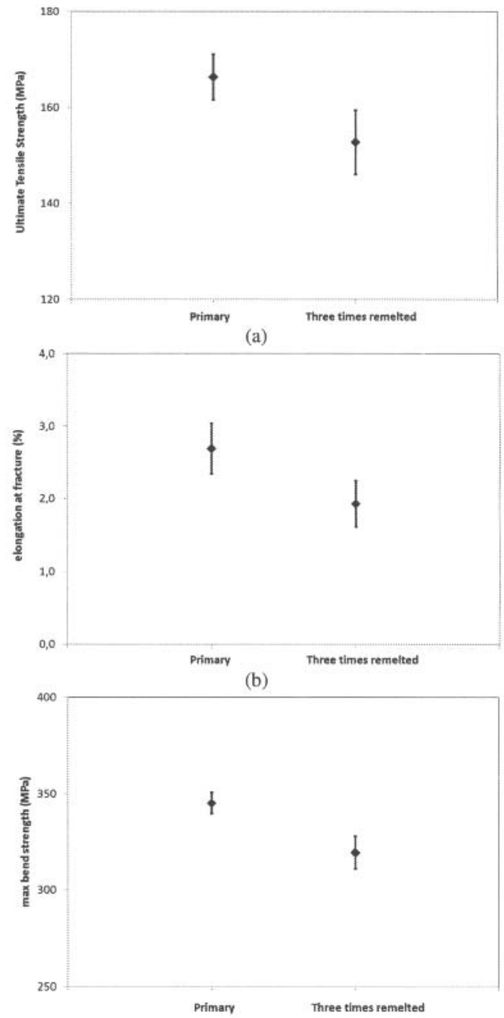
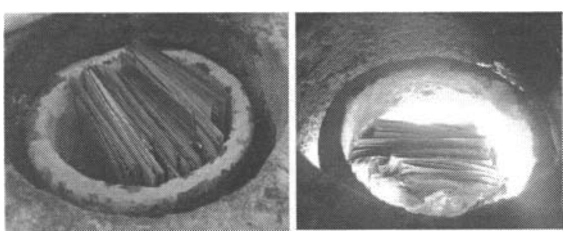


Figure 9: Mechanical test results of the ingot material (a) ultimate tensile strength, (b) elongation at fracture, (c) 3-point bend test

Discussion

An unexpected result concerning metal quality of 3000 was the observation of similar bifilm index values for the melt from the three different surface finish samples. As seen in Figure 5, the bifilm index results for (i) 'untreated', (ii) 'anodized' and (iii) 'anodized + coated' charges were 9 mm, 10 mm and 15 mm, respectively. It was expected that especially the (iii) 'anodized + coated' material would have the worst quality due to the thick oxide layer and the coating. Not surprisingly, since they all had the same bifilm index, the tensile properties of these castings were also similar with ultimate tensile strength around 120 MPa and elongation at fracture around 5% (Fig 7).

These results can be explained as follows: the materials were charged into the crucible in stacks as shown in Figure 10 (a). When the temperature rises inside the crucible, the plates retain their form of stacking due to the rigid oxide structure. However, aluminium with its low melting point compared to the oxide that surrounds it will melt and settle at the bottom of the crucible. After all the material inside the plates is drained to the bottom of the crucible, the surface oxide of the original charge remains and is collected as dross on the surface (Fig 10b). This is schematically shown in Figure 11.



(a) (b)

Figure 10. (a) Charge of the materials in the crucible
(b) Completion of melting and dross formation at the surface

Tests from surfaces (i), (ii) and (iii) employed aluminium from the same original coil. The metal quality proved to be the same for all melting experiments as seen in Figure 6 (i.e. same bifilm index).

This result is also supported by the reduced pressure test results. As seen in Figure 5, RPT samples collected from the melt before skimming have a high bifilm index, which indicates a high content of oxides. When the dross is skimmed off, the melt quality is observed to be constant and good in the next four measurements.

The effect of surface treatments is observed to be critical for the melting yield. The reclaiming (mass) ratios were 96%, 90% and 70% for (i) untreated, (ii) anodized and (iii) anodized and coated materials, respectively (Fig 4). The metal loss was highest in (ii) anodized and (iii) coated materials, as expected.

Overall, there was a good correspondence between bifilm index and the mechanical properties of the coil material. This can be seen in Figures 6 and 7. Interestingly, the correspondence is most clear for the the max bend strength of the sheet material seen in Figure 7. Here a slight decrease in the max bend strength is observed for (iii) 'anodized + coated' material which has the highest bifilm index.

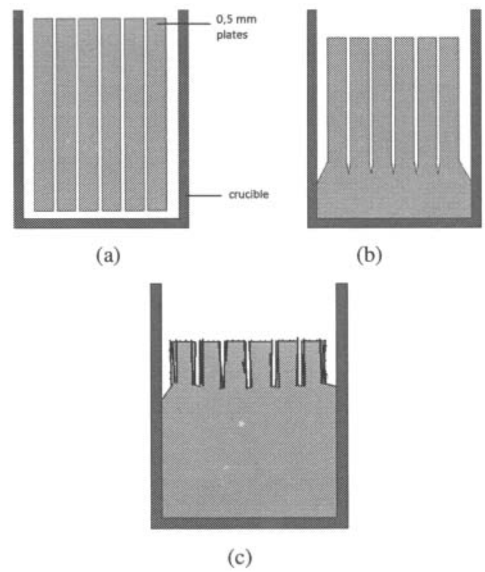


Figure 11. Schematic representation of melting procedure:
(a) Charging of the materials into the crucible
(b) start of the melting, (c) completion of melting and dross formation at the surface

The bifilm index changes from good to bad for the ingot material after three times remelting as shown is given in Figure 8. The mechanical properties also decreased significantly. The reason is probably that removal of oxides by skimming was hardly possible as the remelting procedure was different than the wrought alloy. However, the correlation between bifilm index and mechanical properties of the ingots (cast alloy: A356) is also in good agreement (Figs 8-9).

It is important to note that fluxing or degassing was not carried out. Removal of surface oxide by skimming has a strong effect on melt quality. Since skimming is problematic, metal refining to remove oxides will be even more important for remelting than for primary production.

Conclusions

1. Metal quality after skimming is the same for all three coil materials (i) untreated, (ii) anodized and (iii) anodized and coated.

2. The loss of metal to dross is high for the (iii) anodized+ coated aluminium.

3. There is a good correlation between bifilm index and mechanical properties.

4. Bifilm index of primary cast alloy increased from good to bad after three times remelting, with no skimming. The mechanical properties decreased significantly.

Acknowledgment

The authors acknowledge the financial support of SINTEF for this work. Also thanks are due to Hydro Aluminium Rolled Products AS, Holmestrand and Leif Ivar Koksvik for providing materials, and to Alcoa for supplying the cast material. Thorvald Abel Engh is acknowledged for assistance.

References

1. Gronostajski, J. and A. Matuszak, *The recycling of metals by plastic deformation: an example of recycling of aluminium and its alloys chips.* Journal of Materials Processing Technology, 1999. 92-93: p. 35-41.
2. Tenorio, J.A.S., M.C. Carboni, and D.C.R. Espinosa, *Recycling of aluminum - effect of fluoride additions on the salt viscosity and on the alumina dissolution.* Journal of Light Metals, 2001. 1(3): p. 195-198.
3. Samuel, M., *A new technique for recycling aluminium scrap.* Journal of Materials Processing Technology, 2003. 135(1): p. 117-124.
4. Amini Mashhadi, H., et al., *Recycling of aluminium alloy turning scrap via cold pressing and melting with salt flux.* Journal of Materials Processing Technology, 2009. 209(7): p. 3138-3142.
5. Dispinar, D. and J. Campbell, *Effect of casting conditions on aluminium metal quality.* Journal of Materials Processing Technology, 2007. 182(1-3): p. 405-410.
6. Verran, G.O. and U. Kurzawa, *An experimental study of aluminum can recycling using fusion in induction furnace.* Resources, Conservation and Recycling, 2008. 52(5): p. 731-736.
7. Prakash, M., P. Cleary, and J. Grandfield, *Modelling of metal flow and oxidation during furnace emptying using smoothed particle hydrodynamics.* Journal of Materials Processing Technology, 2009. 209(7): p. 3396-3407.
8. Sleppy, W.C., *Oxidation of molten high-purity aluminum in dry oxygen.* Journal of the Electrochemical Society, 1961. 108(12): p. 1097-1102.
9. Impey, S.A., D.J. Stephenson, and J.R. Nicholls, *Mechanism of scale growth on liquid aluminum.* Materials Science and Technology, 1988. 4(December): p. 1126-1132.
10. Scamans, G.M. and E.P. Butler, *In situ observations of crystalline oxide formation during aluminum and aluminum alloy oxidation.* Metallurgical and Materials Transactions A, 1975. 6A(November): p. 2055-2063.
11. Fuoco, R., et al., *Characterization of some types of oxide inclusions in aluminum alloy castings.* AFS Transactions, 1999. 107: p. 287-294.
12. Tenorio, J.A.S. and D.C.R. Espinosa, *High-temperature oxidation of Al-Mg Alloys.* Oxidation of Metals, 2000. 53(3/4): p. 361-373.
13. Dispinar, D. and J. Campbell, *Critical assessment of reduced pressure test. Part 2: Quantification.* International Journal of Cast Metals Research, 2004. 17(5): p. 287-294.