INFLUENCE OF SILICON IN THE SEGREGATION OF SECONDARY ALUMINUM

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Abstract. *During the using cycle of aluminum products, various impurities are eventually incorporated into the metallic matrix, which promotes devaluation of recycled ingots. In order to make the aluminum reuse more technical and economically viable, it is important do develop new techniques to remove these impurities. This paper presents a study about how the silicon influences the chemical segregation in secondary aluminum ingots. The objective was to study how much segregation occurred and verify its potential to promote the purification of the molten through the accumulation of undesirable elements in a region to be further removed. The analysis of the segregation that occurred shows very promising results about the development of new metallurgical methods to raise aluminum purity. The silicon shows great influence in the phenomenon of inverse macrosegregation, where the impurities are concentrated at the edges of the cast ingot allowing removal by a simple machining process, enhancing purity and consequently increasing added value.*

***Keywords**: Segregation, Aluminum recycling, Impurity.*

1. INTRODUCTION

Aluminum is a highly recyclable material and this process is becoming an essential activity for self supporting industry making activities to become economically viable. To do so, the industrial processes must be optimized in order to maximize resource efficiency (Thomas and Wirtz, 1994; Logozar et al., 2006). In recent decades, because of the environmental protection laws and exponential increase in demand of aluminum across the globe, its production grows rapidly (Hong et al., 2009). The application of aluminum alloys in substitution of steel and cast iron in automobilist industry is rising due to the saves in weight and so, fuel consumption (Miller et al., 2000).

The alloys obtained from the melting of aluminum scrap are called secondary or second fusion alloys (Mello, 2007). Through the life-cycle of aluminum, various impurities are eventually incorporated into the metal matrix (Diniz, 2009). Iron is the most common impurity in aluminum, but any element not intentionally added to the molten metal is regarded as an impurity (ABAL, 2007). Corrections of contaminated alloys are usually made by diluting excess components, with the addition of primary aluminum or high purity alloys, to reach the desired composition. This means costs in the final product.

In the liquid state, the behavior of metals is quite similar where the elements are diluted in the melt. However, due to aspects related to solidification and cooling process, variations in chemical composition may arise from lower temperature regions of the piece. This phenomenon is called segregation (Garcia, 2008).

The segregation can be micro and macro scaled depending on several factors inherited to the system or not. This study is focused on macro-segregation. In normal macro-segregation, considering ideal environmental conditions, the center has a higher concentration than edges because the metal matrix rejects solute due to differences in cooling rates (Garcia, 2008). Opposing to this, when the edges have a higher concentration than the league average, it means that an inverse segregation occurred, caused by a flow of solute-rich liquid from the center to the edges of the piece, due to contractions during the solidification process. Another mechanism is the gravity macro-segregation that occurs when the elements in the melt have high density differences (Müller, 2002).

As recycled aluminum possesses great quantity and variety of elements, studies aiming productivity improvements and cost reduction, in search for sustainability of the process becomes essentials. The lack of appropriate purification techniques is the primary motivational factor of this research.

2. METODOLOGY

The experiments were carried out in the dependences of UTFPR -Ponta Grossa, in the Thermo-transformation Materials Laboratory - CETEM. The manufacturing of the ingot used in these experiments resulted from the fusion in an induction furnace of several types of raw materials. A sample was retrieved when the material was in liquid state and its composition was investigated by spectrometry. Table 1 shows the element percentages of the sample that was considered the initial composition (C_0). The resulting ingot does not fit with any specification for aluminum alloys, since all elements, excepting Al, were considered as impurities. The leak was performed using a ceramic filter in cylindrical cast iron chill 0.1016 m in diameter and 0.360 m height. The cylindrical cast iron chill was inserted into a sand container (Silica sand AFS # 70) and filled to the edge to control the heat exchange.

Samples of the obtained ingot were cut with 0.01 m intervals, totaling 15 samples numbered from the base. After grinding, the samples were analyzed in eight different points, being four in the center region and four in the edge, by a

Metal Lab optical emission spectrometer. A representative sample of the block was analyzed by SEM and evaluated by microanalysis. The work focused on the elements Si, Fe, Cr, Cu, Zn, Mn and Mg, considered impurities.

Table 1. Initial composition of the alloy (C_0).

	Si	Fe	Cu	Mg	Zn	Mn	Ni	Cr	Ti	V	Pb	Sn	Al
Wt.%	**6,57**	**1,34**	**1,01**	**1,1**	**0,07**	**0,2**	**0,34**	**0,02**	0,02	0,01	0,03	0,02	**89,25**

3. RESULTS AND DISCUSSIONS

Figure 1 show the result of spectroscopic analysis of the ingot, where all elements, except aluminum, were considered impurities.

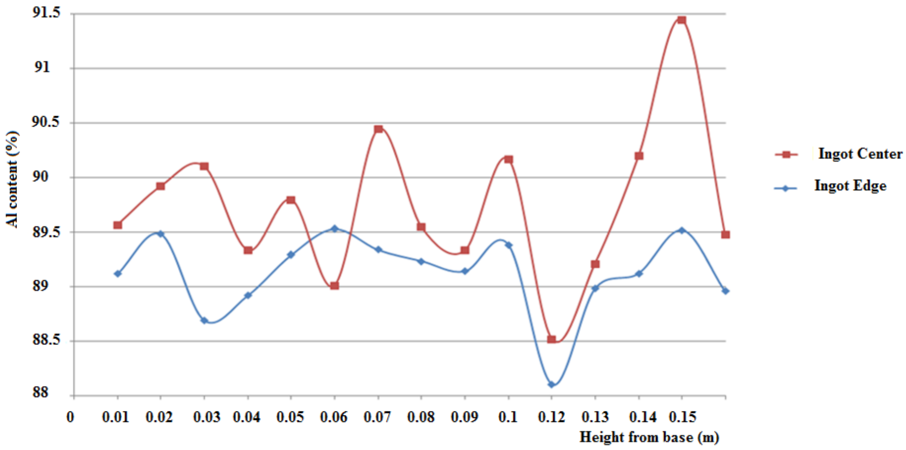


Figure 1. Comparison of aluminum content in the center and in the edges of the ingot.

There is a pattern in the concentration, where the impurities content is higher in the edge. According to previews work (Garcia, 2008) at this type of industrial ingot it is expected a normal segregation, where impurities are concentrated in the center, since it will be the last region to solidify. Therefore the conclusion is that inverse segregation occurred, probably due to solidification contraction.

The amount of aluminum in the sample C_0 (shown in Tab. 1) is 89.25%. The averages in the center region is 89.74% and in the edge 89.12%. Thus, by calculating the difference between them, the segregation of the components was approximately 0.62%. Considering the individual segregation of the elements relative to 0.62%, the representation in the total segregation amount is shown in Table 2.

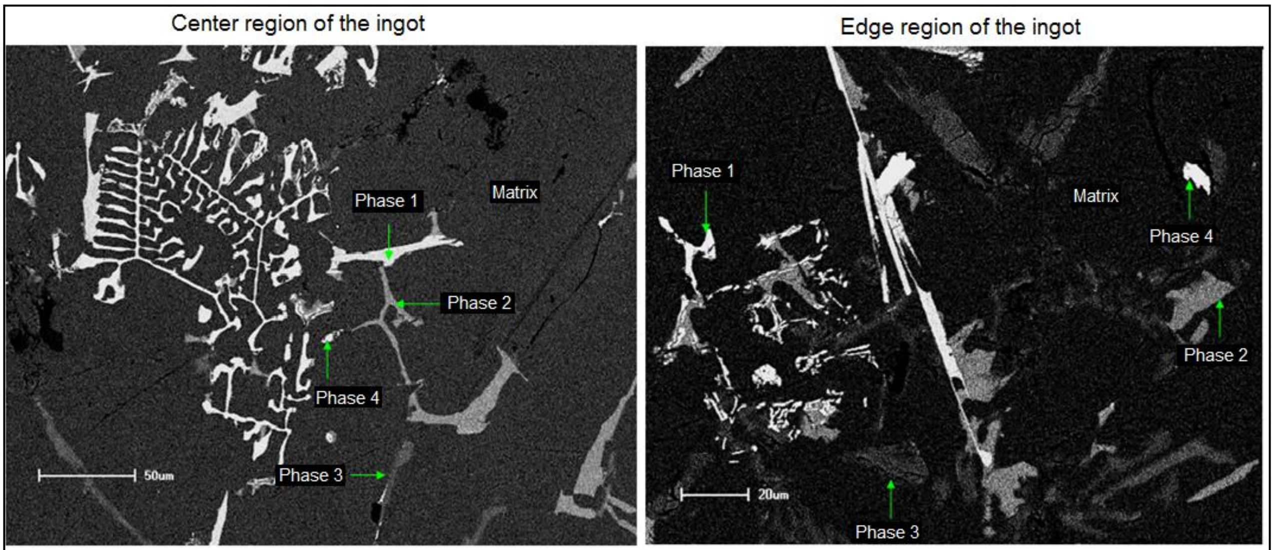
It may be realized that the Si is the most representative element, accounting for 44.68% of the total obtained in the segregation block.

Table 2. percentage contribution of each element in the ingot segregation.

	Center (wt.%)	Edge (wt.%)	Segregation	**Representation in segregation (relative to 0.62 wt.%)**
Si	6,57	6,29	0,28	**44,68**
Fe	1,49	1,40	0,09	**14,16**
Cu	0,92	0,85	0,06	**10,20**
Mg	1,22	1,09	0,12	**19,67**
Zn	0,06	0,06	0,01	**0,84**
Mn	0,22	0,20	0,02	**3,10**
Ni	0,38	0,34	0,04	**6,10**
Cr	0,02	0,02	0,00	**0,77**
Total			0,62	99,52[(1)]

[(1)]: The remaining 0.48% is the segregation of other elements also present.

Analyses by SEM and microanalysis allowed the identification of four phases, as shown in Figure 2. The stage in a "fishbone" resemble those found in previews work (Ferrarini, 2005) identified as $Al_{15}(FeMn)_3Si_2$. This is a stable phase, also called α-AlFeSi. Comparing the analyzed regions, it is observed that in the edge there are formations in needle shape, typical of β-Al_5FeSi (Ferrarini, 2005).



	Center region of the ingot					Edge region of the ingot				
	Matrix	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**	**Matrix**	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**
Mg	1.112	0.414	16.340	0.225	0.516	1.668	0.451	18.413	0.262	0.647
Al	87.026	58.416	43.036	2.769	27.646	90.982	39.027	41.894	2.309	27.298
Si	1.614	16.232	18.500	91.302	0.204	1.638	8.678	23.119	84.738	2.781
Cr	0.237	0.000	0.209	0.000	5.390	0.411	14.763	0.159	0.342	0.149
Mn	4.685	2.506	0.501	0.274	6.081	2.321	1.736	0.637	4.776	9.521
Fe	0.328	21.170	10.616	3.402	14.944	0.983	33.895	4.244	5.212	20.389
Ni	2.500	0.666	8.534	1.084	18.540	1.107	1.303	10.055	1.341	17.789
Cu	2.164	0.596	1.828	0.706	25.320	0.720	0.000	1.044	0.761	20.625
Zn	0.334	0.000	0.436	0.238	1.359	0.170	0.147	0.435	0.259	0.801

Figure 2. SEM images indicating the present phases and its compositions.

4. CONCLUSION

It was observed the inverse segregation of the chemical elements between the center and the edge of the ingot, showing to be viable the development of techniques for removal of metallic impurities in the secondary aluminum.

Intermetalic phases, apparently α-AlFeSi and β-Al_5FeSi, were formed in the center and in the edges of the samples. Once the silicon was the element that most contributed to the segregation and this element constitutes the present phases, it can be concluded that Si have great influence in the phenomenon of macro-segregation.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

ABAL, Guia Técnico do Alumínio, Vol. 11- São Paulo: Associação Brasileira do Alumínio, 2007.

Diniz, A. G. F., "Influência das fontes de alumínio secundário na geração de escória: uma análise estatística". Revista Produção Online, Vol. IX, n.II, p. 284-302, 2009.

Ferrarini, C. F., "Microestrutura e propriedades mecânicas de ligas Al-Si hipoeutéticas conformadas por spray", São Carlos, 2005, 108 f. Tese (Doutorado em Ciência e Engenharia de Materiais). Universidade Federal de São Carlos, 2005.

Garcia, A., "Solidificação: Fundamentos e Aplicações". São Paulo: Editora da UNICAMP, 2008, p. 399.

Hong, J-p., Wang, J., Chen, H-y., Sun, B-d., Li, J-j. and Chen, C., (2010). "Process of aluminum dross recycling and life cycle assessment for Al-Si alloys and brown fused alumina." Transactions of Nonferrous Metals Society of China, Vol. 20, pp. 2155-2161.

Logozar, K., Radonjic, G. and Bastic, M., (2006). "Incorporation of reverse logistics model into in-plant recycling process: A case of aluminum industry." Resources, Conservation and Recycling, Vol. 49, pp. 49-67.

Melo, G. W., "Estudo para minimização e reaproveitamento de escórias geradas na fundição de alumínio". Trabalho de Conclusão de Curso (Graduação) – UTFPR. Curso Superior de Tecnologia em Fabricação Mecânica. Ponta Grossa, 2007.

Miller, W. S., Zhuang, L., Bottema, J., Witterbrood, A. J., Smet, P. De, Haszler, A. and Vieregge, A., (2000). "Recent development in aluminum alloys for the automotive industry." Materials Science and Engineering A, Vol. 208, pp. 37-49.

Müller, A., "Solidificação e Análise Térmica dos Metais". Porto Alegre: UFRGS, 2002, p.278.

Thomas, M. P. and Wirtz, A. H., (1994). "The ecological demand and practice for recycling of aluminum". Resources, Conservation and Recycling, Vol. 10, pp. 193-204.

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