Influence of homogenization on chemical properties of aluminum alloy EN AW-5083

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INFLUENCE OF HOMOGENIZATION ON CHEMICAL PROPERTIES OF ALUMINUM ALLOY EN AW-5083

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The aim of this paper is to estimate the chemical composition homogeneity of six aluminum EN AW-5083 alloy slabs produced by the Direct Chill Process in as-cast and homogenized condition. The homogeneity assessment is based on the content of magnesium (Mg) as a main alloying element.

The experimental part of this work is based on the analysis of Mg content on previously defined positions within the cross-sectioned plates taken from the slabs' fronts and rears. The determination of chemical composition homogeneity was based on the Latin square experiment design. The statistical processing enabled the determination of the difference in the cross-section of each individual plate. The chemical homogeneity of the slabs as a whole was evaluated by comparing the results from the slabs' fronts and rears. The significance and influence of homogenization on the magnesium content was quantified by comparison of the obtained measurement results for the as-cast and homogenized state of the tested EN AW-5083 alloy.

The obtained results indicate that the Mg content of all melts and all average values of magnesium content in as-cast and homogenized state per individual charges are within the values prescribed by the norm. A small deviation in the magnesium content was detected in the first three tested alloys in the homogenized state (3112, 3113, 3114) as well as decrease in Mg content from the melt to as-cast and homogenized slabs due to oxidation loss. The average value of Mg loss for all six charges is: during casting from the amount of Mg in the melt to the cast slab 0.18 %, additional Mg loss of 0.14 % during the homogenization, while the average total loss of magnesium is 0.32 %.

Keywords: aluminium alloy EN AW-5083, chemical composition homogeneity, content of magnesium, Direct Chill Process

Introduction

The EN AW-5083 is an aluminum (Al) alloy with magnesium (Mg) as the main alloying element. According to EN 573-3 standard it is designated as EN-AW AlMg4.5Mn0.7. (Google, "EN 573-3: 2002.") This alloy is characterized by low specific weight, high mechanical properties, and resistance to corrosion in fresh and seawater environments, provided that the impurity elements are reduced to permissible values. (Davis, *ASM Specialty Handbook: Aluminum and Aluminum Alloys*, 351-416.) The semi-products in the form of slabs are produced by a semi-continuous vertical Direct-Chill Process ensuring homogeneity and continuous quality. (Eskin, *Physical Metallurgy of Direct Chill Casting of Aluminium Alloys*, 1-18.) The finished products for the automotive and transportation industry, shipbuilding, as well as manufacturing of various types of products and pressure vessels are obtained by subsequent thermo-mechanical processing of the slabs. The use of Al-alloys in the construction of ship halls and superstructures enabled a weight reduction of approximately 50 % increasing ship buoyancy, speed, and stability. (Krzysztof. "Mechanical," 47.) Alternatively, it enabled increase in the ship's load carrying capacity while maintaining the same buoyancy. The development of microstructure and macrostructure, physical, mechanical, and chemical properties are affected by several processing parameters such as pouring rate and temperature, melt height in the crystallizer, cooling water flow and temperature as well as melt processing parameters like nucleation potential (inoculation), gaseous and non-metallic inclusion content (filtering, degassing). Furthermore, adequate casting parameters ensure continuous quality and soundness of both semi-products and final products. The solidification and the grain structure in as-cast condition have a direct influence on the subsequent processing and properties of the final product. Since the slabs in as-cast condition are characterized by heterogeneous microstructure, an appropriate heat treatment in form of homogenization is performed to obtain standard microstructure, mechanical and chemical properties.

It is well known that homogenization significantly affects the residual stress removal, segregation reduction, spheroidization and solidification of primary microstructure constituents, as well as dissolution of phases with low-solubility. More detailed insight into development of slab structure and optimization of processing parameters is obtained through examination and quantification of parameters that determine the degree of homogeneity and/or anisotropy of cast and homogenized slabs (chemical composition, number of grains per unit area, mechanical properties, electrical conductivity, hardness and composition, distribution and amount of intermetallic phases and porosity). (Dolić, "*Homogeneity of 5083 Al-Alloy Slabs,*" 1-183., Dolić, "*Influence of Solidification,*" 1-269., Dolić and Zovko Brodarac, "Evaluation of EN AW-5083 Aluminum Alloy Homogeneity," 429-439., Dolić, Markotić, and Unkić, "Structural Homogeneity of Direct-Chill Cast Ingots," 491-495., Dolić, Bunjan, and Kozina. "Correlation of Mechanical and Microstructural Properties," 206-219., Dolić, Zovko Brodarac, and Kozina. "Evaluation of EN AW-5083 Aluminium Alloy Ingots," 57.)

Materials and methods

The investigation of chemical properties homogeneity was carried out in six slabs cast by the Direct Chill Process. The slabs 1430 x 520 x 5100 mm in size were manufactured from six different melts of EN AW-5083 alloy (designations 3112, 3113, 3114, 3116, 3117, 3120). Before casting, the melt was refined with an argon and chlorine mixture in an Alpur unit. The grain refinement was performed through the addition of Al-Ti5-B1 master alloy with an average amount of 1.9 kg/t melt. The inoculation procedure comprehended the addition of small bars of the master alloy to the casting furnace, followed by the introduction of master alloy wire in a launder positioned in front of the Alpur unit. For the purpose of this investigation a semi-industrial homogenization of EN AW-5083 cast slabs was performed in the "AVS250 Durferrit" salt bath (a mixture of alkaline nitrites and alkaline nitrates) at a temperature of 520 °C for 10 hours. (Dolić, "*Influence of Solidification,*" 83-92., 102-103., Dolić and Zovko Brodarac, "Evaluation of EN AW-5083 Aluminum Alloy Homogeneity," 430.) Since it was impossible to analyze their entire cross-section, the transverse plates were cut from the fronts and rears of Al slabs.

The sampling was performed on the cut plates in accordance with Latin square experiment design (Dolić, "*Influence of Solidification,*" 100., Dolić and Zovko Brodarac, "Evaluation of EN AW-5083 Aluminum Alloy Homogeneity," 430.). The analysis of Mg content in the as-cast condition was performed on the lower halves of cross-cut plates (1FC - 36 FC, 1RC - 36 RC), while the analysis of the samples in homogenized condition was conducted on identical, mirror-image places on the upper halves of plates (1FH - 36 FH, 1RH - 36 RH). The samples cut from the plates were designated as: specimen number, letters F (ingot front section) or R (ingot rear section), condition C (as-cast) or H (homogenized). The chemical composition of all samples was determined using an optical emission spectrometer (OES) "ARL" on a thin plate (5 mm thick), measuring 30 × 30 mm cut from each section. The mean value was calculated. Although the chemical composition analysis included larger number of chemical elements, for the purpose of determining the chemical homogeneity of Al slabs, only the Mg content was considered. After the results were statistically processed, the difference in the Mg content across the section of each individual plate was determined. The chemical homogeneity of the slabs as a whole was evaluated by comparing the results from the front and rear sections. Finally, the impact of homogenization on the Mg content was quantified by comparing the obtained data for the as-cast and homogenized metallurgical condition.

Results and discussion

Chemical composition analysis of EN AW-5083 alloys, given in previous investigations (Dolić, "*Homogeneity of 5083 Al-Alloy Slabs,*" 73., Dolić, "*Influence of Solidification,*" 92.), indicates that all measured values are in accordance with EN AW-5083 standard. (Google, "EN 573-3: 2002.") Table 1 shows the mean values of the Mg content for all samples in the as-cast and homogenized condition taken from the fronts and rears of the tested slabs.

Table 1 The Mg content in as-cast and homogenised samples

Sample	Mg, [%]	Sample	Mg, [%]	Sample	Mg, [%]	Sample	Mg, [%]
1FC; 1RC	3.83; 3.98	19FC; 19RC	4.05; 3.89	1FH; 1RH	3.66; 3.88	19FH; 19RH	4.04; 4.06
2FC; 2RC	4.03; 4.18	20FC; 20RC	4.28; 4.22	2FH; 2RH	3.83; 4.02	20FH; 20RH	4.23; 4.20
3FC; 3RC	3.82; 4.31	21FC; 21RC	4.27; 4.41	3FH; 3RH	3.73; 3.75	21FH; 21RH	4.12; 4.22
4FC; 4RC	4.17; 4.03	22FC; 22RC	4.01; 4.23	4FH; 4RH	3.93; 3.89	22FH; 22RH	3.99; 4.06
5FC; 5RC	4.08; 4.21	23FC; 23RC	4.12; 4.21	5FH; 5RH	3.93; 3.83	23FH; 23RH	3.97; 3.97
6FC; 6RC	3.93; 4.28	24FC; 24RC	3.72; 3.94	6FH; 6RH	3.79; 4.08	24FH; 24RH	3.81; 3.89
7FC; 7RC	3.91; 3.98	25FC; 25RC	4.05; 4.16	7FH; 7RH	3.62; 3.95	25FH; 25RH	3.97; 3.95
8FC; 8RC	4.05; 4.47	26FC; 26RC	4.27; 4.59	8FH; 8RH	3.96; 4.07	26FH; 26RH	4.19; 4.31
9FC; 9RC	4.57; 4.12	27FC; 27RC	4.11; 4.23	9FH; 9RH	3.88; 4.01	27FH; 27RH	3.98; 4.03
10FC; 10RC	4.38; 4.51	28FC; 28RC	4.15; 4.23	10FH; 10RH	4.07; 4.20	28FH; 28RH	4.00; 3.99
11FC; 11RC	4.14; 4.63	29FC; 29RC	4.06; 4.27	11FH; 11RH	3.97; 4.36	29FH; 29RH	4.01; 4.08
12FC; 12RC	3.87; 3.90	30FC; 30RC	4.13; 3.77	12FH; 12RH	3.73; 3.92	30FH; 30RH	4.05; 3.92
13FC; 13RC	3.68; 4.00	31FC; 31RC	3.99; 4.31	13FH; 13RH	3.62; 3.82	31FH; 31RH	3.83; 4.05
14FC; 14RC	4.23; 4.25	32FC; 32RC	4.05; 4.10	14FH; 14RH	4.13; 4.24	32FH; 32RH	4.04; 3.89
15FC; 15RC	4.29; 4.38	33FC; 33RC	3.93; 4.17	15FH; 15RH	4.19; 4.23	33FH; 33RH	3.98; 4.03
16FC; 16RC	4.31; 4.54	34FC; 34RC	3.91; 4.14	16FH; 16RH	4.15; 4.55	34FH; 34RH	4.02; 4.08
17FC; 17HC	4.18; 4.22	35FC; 35RC	4.12; 4.25	17FH; 17RH	3.98; 4.15	35FH; 35RH	4.09; 4.00
18FC; 18RC	3.87; 3.80	36FC; 36RC	4.01; 3.39	18FH; 18RH	3.67; 3.84	36FH; 36RH	3.99; 3.88

The mean values for each plate taken from the front and rear of the slabs ($\overline{Mg}_{,FC}$, $\overline{Mg}_{,RC}$, $\overline{Mg}_{,FH}$, $\overline{Mg}_{,RH}$), as well as the mean values of the Mg content for the front and rear of as-cast and homogenized plates ($\overline{Mg}_{,C}$, $\overline{Mg}_{,H}$) are given in Table 2. Comparison of the Mg content redistribution in as-cast (Dolić, "*Homogeneity of 5083 Al-Alloy Slabs,*" 89-92.) and homogenized slabs (Dolić, "*Influence of Solidification,*" 175-177.) with respect to their front and rear as well as height and width of the plates indicate no significant deviation (Table 2).

This is also confirmed by coefficients of variation (V) (Dolić, "*Homogeneity of 5083 Al-Alloy Slabs,*" inclosure 8-4., Dolić, "*Influence of Solidification,*" 257.), mean coefficients of variation for the front and rear of the as-cast and homogenized slabs ($\bar{V}_{,FC\%Mg}$, $\bar{V}_{,RC\%Mg}$, $\bar{V}_{,FH\%Mg}$, $\bar{V}_{,RH\%Mg}$) and total mean coefficient of variation for as-cast and homogenized condition ($\bar{V}_{,C\%Mg}$, $\bar{V}_{,H\%Mg}$) (Table 2). Additionally, a decrease in the $\bar{V}_{,H\%Mg}$ coefficient of variation (Table 2) indicates that more even distribution of Mg has been achieved through the entire slab after homogenization. This can also be observed through the degree of Mg segregation at the macro level as the ratio between the maximum and minimum concentrations of Mg, (Mg_{max}/Mg_{min}), Table 2. The Mg segregations are significantly reduced after the homogenization heat treatment.

Table 2 Mean values of Mg content, mean coefficients of Mg content variation and the degree of Mg segregations at the fronts and rears of the as-cast and homogenized slabs

Content Mg [%]		$\bar{V}_{,\%Mg}$ [%]		Mg_{max}/Mg_{min} [%]	
$\overline{Mg}_{,FC}$	4.07	$\bar{V}_{,FC\%Mg}$	3.74	$Mg_{max}/Mg_{min}(FC)$	1.24
$\overline{Mg}_{,RC}$	4.19	$\bar{V}_{,RC\%Mg}$	4.20	$Mg_{max}/Mg_{min}(RC)$	1.35
$\overline{Mg}_{,C}$	4.13	$\bar{V}_{,C\%Mg}$	3.97	$Mg_{max}/Mg_{min}(C)$	1.30
$\overline{Mg}_{,FH}$	3.95	$\bar{V}_{,FH\%Mg}$	3.73	$Mg_{max}/Mg_{min}(FH)$	1.17
$\overline{Mg}_{,RH}$	4.04	$\bar{V}_{,RH\%Mg}$	3.37	$Mg_{max}/Mg_{min}(RH)$	1.21
$\overline{Mg}_{,H}$	4.00	$\bar{V}_{,H\%Mg}$	3.55	$Mg_{max}/Mg_{min}(H)$	1.19

The decrease in Mg content is observed by comparing the mean content of Mg measured at each individual tested plate in as-cast $\overline{Mg}_{,FC}(3112\text{-}3120)$ = 3.88 - 4.21 % and $\overline{Mg}_{,RC}(3112\text{-}3120)$ = 4,05 - 4.46 %) (Dolić, "*Influence of Solidification,*" 178.) and homogenized ($\overline{Mg}_{,FH}(3112\text{-}3120)$ = 3.85 - 4.06 % and $\overline{Mg}_{,RH}(3112\text{-}3120)$ = 3.95 - 4.26 %) (Dolić, "*Influence of Solidification,*" 178.) condition. This decrease in Mg content in homogenized condition is observed at the fronts and rears of all 6 charges. This is indicated by the comparison of the total arithmetic means of the Mg content for fronts and rears of as-cast ($\overline{Mg}_{,FC}$ = 4.07 % and $\overline{Mg}_{,RC}$ = 4.19 %) and homogenized slabs ($\overline{Mg}_{,FH}$ = 3.95 % and $\overline{Mg}_{,RH}$ = 4.04 %) for all tested charges and the total mean Mg content for the as-cast and homogenized state ($\overline{Mg}_{,C}$ = 4.13 % and $\overline{Mg}_{,H}$ = 4.00 %), Table 2. Figure 1 shows the mean values of the Mg content from the front and rear plates of each tested slab and the Mg content measured in the melt during the casting of slab 0.5 m in length for each individual charge.

The dashed line represents the minimum and maximum Mg content determined by the standard for EN AW-5083 (4.0 - 4.9 % Mg) (Google, "EN 573-3: 2002."). It can be seen that the Mg content in all melts and all the mean values of the Mg content in the as-cast and homogenized condition per individual charge are within the standard limits, except for small deviations for the first three tested alloys (3112, 3113, 3114) in the homogenized condition. The Figure 1 shows decrease in Mg content from the melt to the as-cast slab and to the homogenized samples for all six charges.

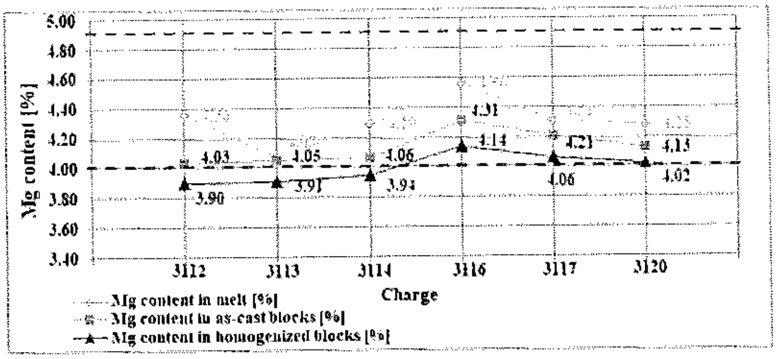

Figure 1 The average Mg content in the slab (in the as-cast and homogenized samples) and Mg content in the melt for each individual charge

Further insight, provided by Figure 2, shows the loss due to oxidation *O(M-C)*, *O(C-H)* i *O(M-H)*. The average value of Mg loss for all six observed batches is: during casting from the amount of Mg in the melt to the cast slab *O(M-C)* 0.18 %, additional loss of Mg during the homogenization of *O(C-H)* 0.14 %, while the average total loss of magnesium is *O(M-H)* 0.32 % (Figure 2). Due to the very unfavourable surface area/mass ratio of slabs, the oxidation loss during homogenization in semi-industrial conditions is higher compared to the established industrial practice. The reduced average value of the Mg content in the slab compared to the content in the melt is a consequence of Mg oxidation occurring during melt processing and casting.

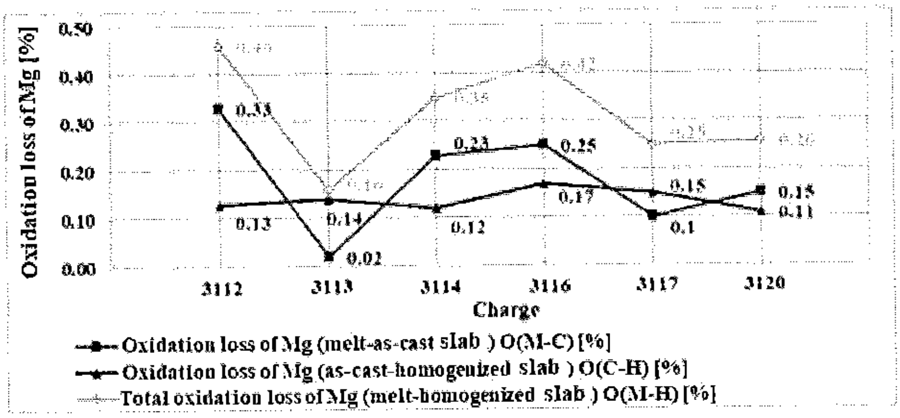

Figure 2 The oxidation loss of Mg in EN AW-5083 alloy: melt to as-cast slab O(M-C), during homogenization in salt bath O(C-H) and total oxidation loss O(M-H)

Conclusion

The aim of this investigation is to establish the chemical properties of tested slabs by determining the distribution of Mg content. Also, the consistency in obtaining the necessary Mg content in an individual slab and its oxidation loss in relation to the final furnace analysis is considered. Obtaining a constant content and even distribution of Mg within the slab indicates properly performed alloying and melt homogenization, as well as adequate melt processing and casting parameters, as well as the repeatability of the casting process.

Analysis of Mg content in individual charge revealed that the mean values of the Mg content obtained at the front of the slabs are generally lower than the mean values measured at the analogous locations at the slab's rears. This might be the consequence of non-stationary state at the beginning of the casting process. Considering a number of controlled and uncontrolled production parameters (input material structure, alloying method, melting sequence and Mg oxidation, casting parameters, etc.) it is understandable that Mg content varies between the charges.

It should be noted that individual values of the Mg content at the front of the slabs were below the values determined by the EN AW-5083 standard, although the total mean values for the fronts and rears of the slabs met the minimum criteria. This indicates the rational use of master alloy, consistent method of alloying and homogenization of the melt.

The comparison of the mean value of the Mg content of the front and rear of each slab or charge with the final melt sample indicates oxidation loss of approximately 0.21 %. This should be taken into account when defining the required minimum value of Mg during the melt testing. It is also necessary to account for all subsequent oxidation losses during further processing of the slabs. The additional research is required to obtain more detailed insight into chemical homogeneity of the slabs as well as macro and micro segregation.

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