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ANALYSIS OF STRUCTURAL AND MECHANICAL CHARACTERISTICS OF THE EN AW-4043 ALLOY INGOTS

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Abstract

This study presents an analysis of the characteristics of ingots made from the EN AW-4043 alloy. Surface defects, such as impurities and porosity, have been identified. Porosity is also present throughout the cross-section of ingots, particularly in the central zone, which solidifies last. The pores occupy a small part of the inter-dendritic spaces of solid solution, where the eutectic microconstituent is also located. These findings affect the fracture surface topography, as well as the distribution of density index and hardness on the ingot cross-section. The results obtained indicate the need for control and optimization the entire casting process and treatment of liquid metal.
Keywords*: EN AW-4043 alloy, casting, ingot, microstructure, porosity, density index, hardness*

1. INTRODUCTION

The Al-Si alloys find extensive application in the automotive and aerospace industries due to their excellent castability, high specific strength, good corrosion resistance, wear resistance, low coefficient of thermal expansion and high recyclability [1,2].

The use of hypoeutectic Al-Si alloys as the structural materials is determined by their physical and mechanical properties depending on the chemical composition, casting conditions, microstructure, and presence of defects [2]. The microstructure of these alloys predominantly consists of dendrites of α solid solution and Al-Si eutectic [3]. The size, morphology, and distribution of microstructural components determine the level of mechanical properties [4,5]. The presence of casting defects, most commonly gas porosity and oxide inclusions, causes undesirable variation in mechanical characteristics across the cross-section, thereby degrading the performance of cast element [6].

In this study, an analysis was conducted on the fracture surface, microstructure, porosity, and hardness of ingots made of the EN AW-4043 alloy.

2. EXPERIMENTAL

The aluminum alloy EN AW-4043 (AlSi5) was selected for this investigation. Casting was performed using an ICM-8 type machine with the primary air cooling. The molds used for casting were made of grey cast iron. The ingots had the following dimensions: 540 × 115(85) × 55 mm. Figure 1 shows the ingot along with the position and appearance of samples prepared for the planned investigations.

To investigate the fracture surface, the ingot was broken by the three-point bending. The bending was performed on a Heckert FP100 universal testing machine, with the load applied in the center of upper surface of ingot and supports, placed on the grooves at the ends of the ingot lower surface.

Microstructural investigation was conducted in the cross-section of ingot, specifically on three samples cut from the middle of ingot (Figure 1b). The sample locations were chosen to correspond to the zones with the slowest cooling rates to adequately identify the microstructure. Chemical etching was done using 1% HF solution. The microstructures were captured using a ZEISS optical microscope with a magnification of 100×.

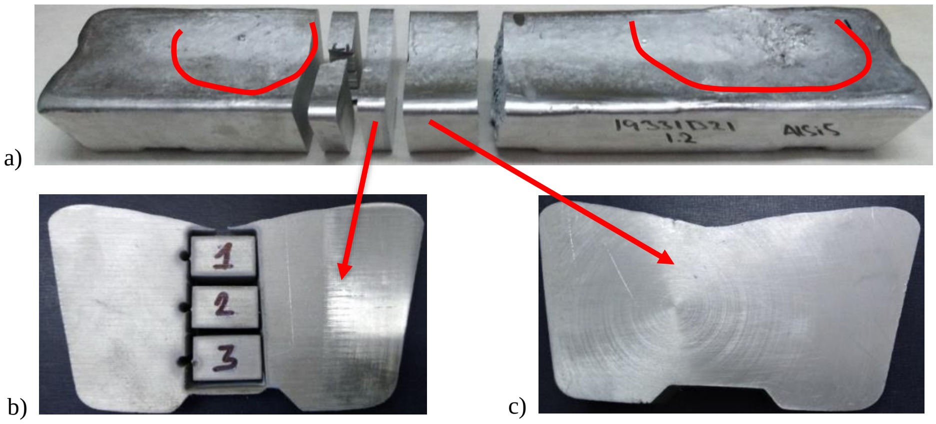


Figure 1. *Ingot (a) and cut samples (b and c) for the planned investigations*

Porosity was analyzed using a density index. This procedure was conducted on samples used for microstructural examination. For this purpose, the masses of all three samples were measured on an analytical balance with the accuracy of 0.001 g, and their volumes were measured using the water displacement method with the accuracy of 0.05 ml.

The hardness testing across the cross-section of ingot was carried out using the Brinell method on an Innovatest 3000LDB device. Testing was conducted with a ball diameter of 5 mm and force of 1225 N, applied for 30 seconds.

3. RESULTS AND DISCUSSION

The areas with altered surface condition, due to the presence of surface pores and adhesive impurities can be observed on the upper surface of ingot (as indicated in Figure 1a). Porosity and impurities are common irregularities arising from the improper treatment of liquid metal and/or suboptimal casting technology. Therefore, it is necessary to verify the conditions and parameters of the liquid metal preparation technology, casting parameters, and cooling conditions.

Figure 2 depicts the fracture surfaces resulting from the three-point bending of the ingot. Surface topography is utilized for the fracture surface characterization, classification, and defining conditions for a decohesion mechanism. No internal cracks or cavities are observed on these surfaces. The fracture surface exhibits the typical characteristics akin to those of brittle materials fractured under static tensile forces. Fracture in such materials can be both trans-granular and inter-granular [2]. The microstructure of inter-granular fracture in the AlSi7Mg alloy, depicted in Figure 3 [2], confirms the fracture type of these materials.

Specifically, the surface topography of brittle intergranular fracture is characterized by a rough surface in the central zone of ingot (as marked in Figure 2). This zone, when the cast is in molds, solidifies last, providing conditions for intensified dendrite growth and formation of a coarse structure. The initial crack originates precisely in the central part of ingot and rapidly propagates along the dendrite boundaries within the brittle eutectic microconstituent, resulting in a fracture, occurring immediately at the onset of plastic deformation during bending.

Microstructural examination was conducted on the front surfaces of samples 1, 2, and 3 (Figure 1b). Microstructures at numerous points were analyzed on each sample. Figure 4 shows the characteristic microstructures for each sample. The typical microstructure of the cast EN AW-4043 alloy with dendrites of the primary solid solution and eutectic along the dendrite boundaries is evident in all images, fulfilling the main requirement for the ingot microstructure control. No oxide inclusions were observed. However, the presence of pores is noticeable in a broader region of the ingot cross-section. In the microphotographs, pores appear as darkened areas with boundaries that completely fill the space between dendrites (Figure 5a). Porosity is visible even to the naked eye, and is characterized by the prominent spots in the central part of ingot cross-section (as indicated in Figure 5b).

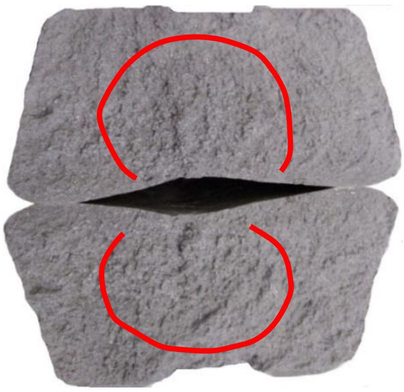


Figure 2. Appearance of fracture surfaces

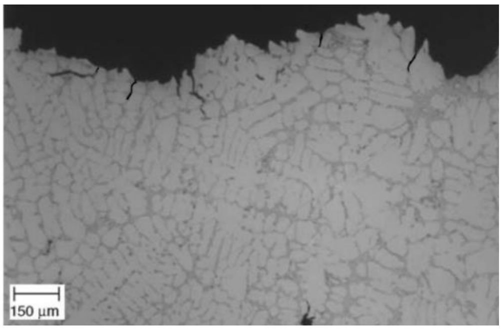
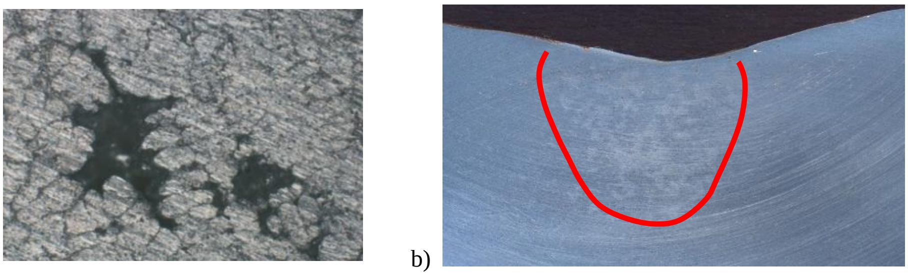


Figure 3. *Profile of intergranular fracture with a central crack through the inter-dendritic region and secondary cracks [2]*

a) b) c)

Figure 4 *Microphotographs at selected positions of samples: 1 (a), 2 (b), and 3 (c)*



a) b)

Figure 5. *Typical appearance of porosity (magnification 200x) (a) and ingot cross-section with noticeable gas porosity (b)*

Porosity across the ingot cross-section is quantified using a density index. The procedure consists of casting samples in both air and vacuum environments, followed by measuring the mass and volume of samples, calculating density, and comparing the obtained density values. It was considered justifiable to apply the procedure analogously to the already prepared samples for the microstructural testing, as they reliably represent the porosity state in the separated zones throughout the ingot thickness. The results are presented in Table 1.

It is evident that sample 1, which encompasses the most significant part of the porosity zone, has the lowest density and density index of 8.6% and 6.1%, respectively, compared to the samples 2 and 3. The density index between the samples 2 and 3 is 2.7%, and is considerably lower than the previous two. Indices relative to the mean density value range from 1.1% to 5.3%. If the widely accepted practice is followed, where the index value lower than one indicates the excellent refinement quality [1], then these results significantly deviate from this value.

Table 1. *Measurement results of sample mass and volume, density values, and density indexes*

Sample	Mass [g]	Volume [cm^3]	Density (ρ) [g/cm^3]	Density indexes, [%]		
				$(\rho_2 - \rho_1) / \rho_2$	$(\rho_3 - \rho_1) / \rho_3$	$(\rho_2 - \rho_3) / \rho_2$
1	9.462	3.7235	2.541	8.6	6.1	2.7
2	10.238	3.6827	2.780			
3	10.939	4.0420	2.706			
Mean density (ρ_m)			2.676	$(\rho_1 - \rho_m) / \rho_1$	$(\rho_2 - \rho_m) / \rho_2$	$(\rho_3 - \rho_m) / \rho_3$
				5.313	3.741	1.109

Hardness was measured in the multiple positions across the cross-section of the ingot. The positions of measurement points were chosen in accordance with the standard-prescribed distances between the indent centers and distance from the indent center to the edge of sample (Figure 6a). For a more detailed characterization of the high porosity zone, tests were also conducted on the other side of plate (Figure 6b). It is apparent that the hardness values for the majority of measurement points fall within the range of 53-56 HB. Exceptions are the three values in a high porosity zone, which are 45.9, 34.8, and 36.8 HB. These three results further confirm the presence of porosity, considering its significant impact on the mechanical properties of pronounced deterioration.

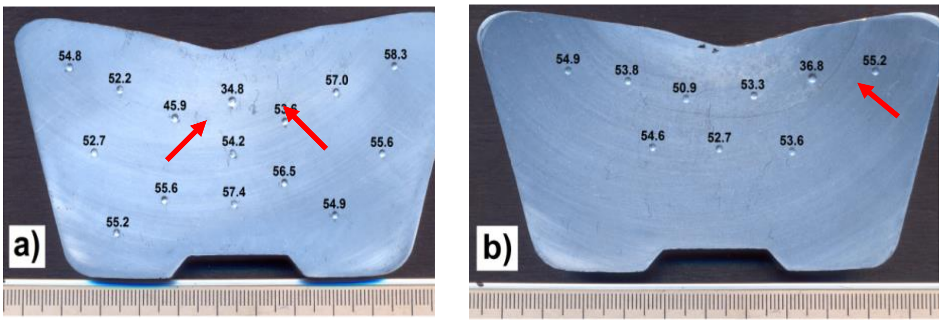


Figure 6 *Hardness measurement results on the front (a) and back (b) sides of the plate cut from ingot*

4. CONCLUSION

The analyses conducted on the EN AW-4043 alloy ingot have shown that, to prevent unwanted surface defects, it is essential to meticulously control the entire casting process. The mean density index value, across the ingot cross-section, is beyond the optimal limits, indicating the pronounced structural porosity. This is a result of inadequate degassing intensity, indicating the need for additional refining o liquid metal and adjustment the process parameters to ensure quality in accordance with the required standards.

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