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Study of Nonmetallic Inclusions in Aluminum–Silicon Alloys

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Abstract

In this article, a study of nonmetallic inclusions introduced during the casting process of the aluminum–silicon alloy is presented. The samples were investigated using a scanning electron microscope to find the chemical composition and X-ray tomography to check the volumetric content of the non-metallic inclusions. The samples were made from $AlSi_7Mg$ al-loy, used for car wheels, with 7% weight content of Si, 89% of Al, and 0.3% of Mg. The main goal of our investigations was to find out the chemical composition of the impurities and to identify the stage of the casting process at which the impurities are introduced.

Keywords

aluminum–silicon alloy, nonmetallic inclusions, scanning electron microscopy, X-ray tomography

1. Introduction

Aluminum–silicon alloys are widely used in automotive, aviation, and other industries because of its lightness, high resistance to corrosion and high wear resistance, better fluidity during casting, high strength-to-weight ratio, low thermal expansion coefficient, heat tractability, and improved mechanical properties at different temperatures. Aluminum–silicon alloys can be used in high-wear applications such as pistons, cylinder liners, and internal combustion engine blocks, and they are also used to produce aluminum car wheels [1–4].

During the casting process of the car wheels, the nonmetallic inclusions can be noticed. Nonmetallic inclusions occur as a result of carelessly conducted remelting of the charge material. Previous studies focus mostly on the influence of the impurities on machinability of the aluminum–silicon alloys castings and pores formation [5-7]. In such cases, works estimate the volumetric content of the impurities and pores in the alloy. The results were based on quantification from optical and scanning electron microscopic (SEM) images.

In this article, we investigated the samples made from AlSi7Mg alloy with 7% weight content of Si, 89% of Al, and 0.3% of Mg. The studied samples contain some nonmetallic inclusions introduced on various stages of processing of the alloy and production. The samples were investigated using a SEM and X-ray tomography.

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2. Chemical Composition of the Nonconductive Inclusions

Three samples, cut out of three different aluminum car wheels, were investigated. In Figure 1, an example of such a nonmetallic inclusion by optical microscope is shown.

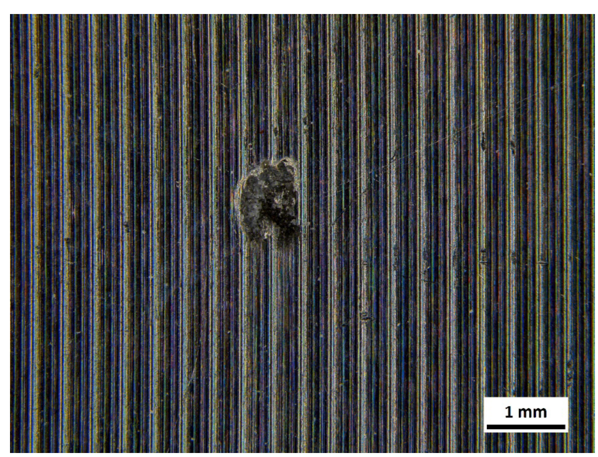


Figure 1. An example of nonmetallic inclusion in the aluminum–silicon alloy. Image obtained using optical stereographic microscope.

The samples were cut from different places of the aluminum alloy wheel. The first sample contained two locations with nonmetallic inclusions on its surface. The second sample also contained two locations, and the third sample contained three locations with nonconductive inclusions. In Figure 2, the microphotographs

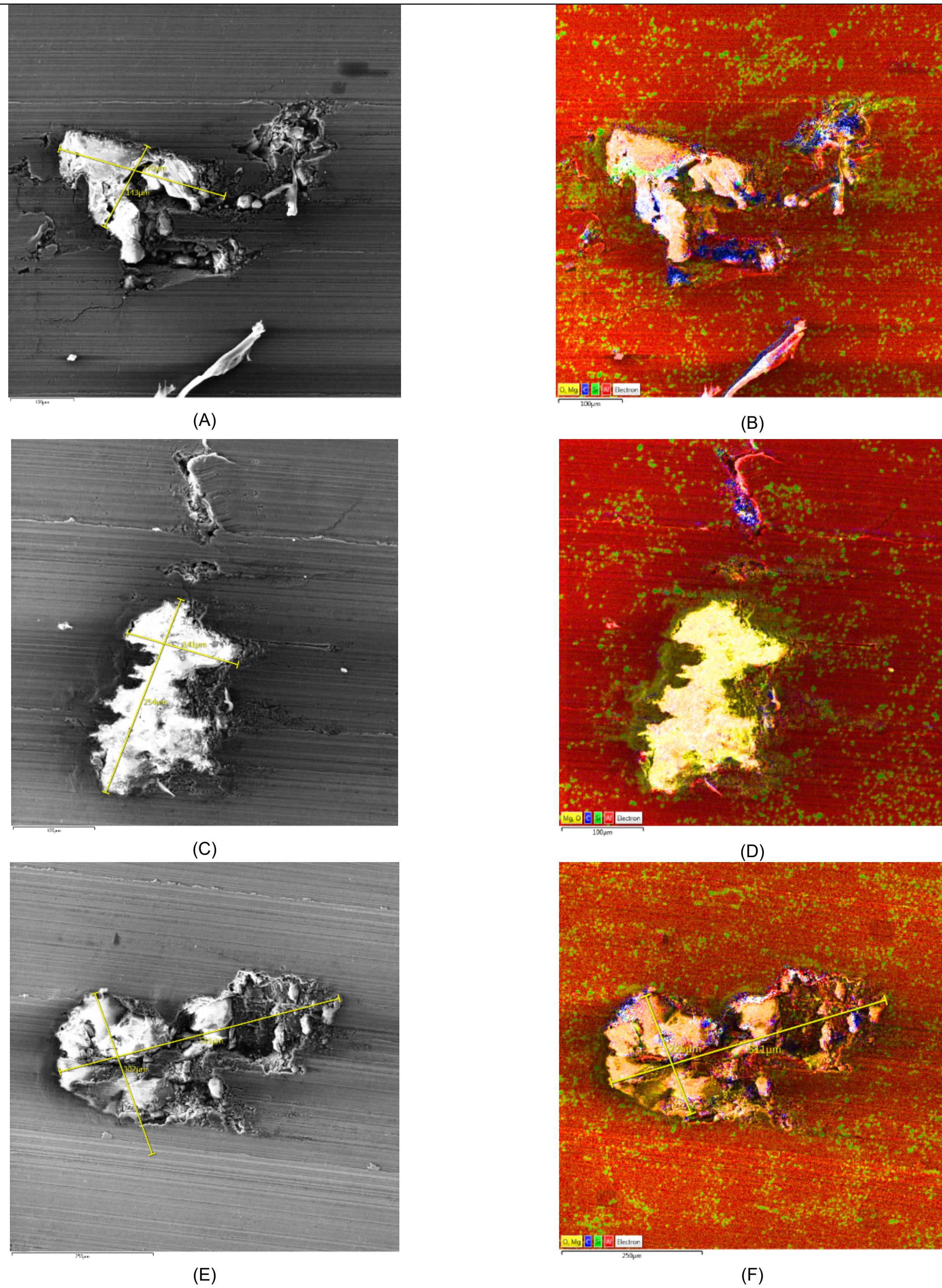


Figure 2. SE-SEM images **(A, C, E)** and chemical element maps **(B, D, F)** for three inclusion sites on the surface of the sample. The chemical elements in the images **(B, D, F)** are color coded as follows: aluminum (red), carbon (blue), silicon (green), oxygen, and magnesium (yellow).

of secondary electrons (SE) and SEM of the nonmetallic contaminants in sample 3 are shown. The inclusions have size ranges from 20 mm to 1.5 mm in length. The contaminants can be seen as black spots on a shiny machined surface of the sample. The inclusions have different structures than the aluminum alloy – irregular with cracks and porous regions.

The investigations using the SEM with energy-dispersive X-ray spectroscopy detector (SEM-EDS) allowed to identify the chemical composition of the nonmetallic inclusions. Microanalysis of the nonmetallic inclusions showed that they are formed mostly of aluminum and magnesium oxides (Al_2O_3 and MgO), respectively. In addition, some of the particles were made out of carbon, most possibly introduced to the surface during the precasting preparation process.

The SE-SEM images and the chemical elements maps are shown in Figure 2 for three inclusion sites with chemical elements as follows: aluminum (red), carbon (blue), silicon (green), oxygen, and magnesium (yellow). The chemical elements maps highlight the difference between the aluminum alloy surface with irregular distribution of platelike silicon precipitates and the nonconductive inclusions with highly irregular shapes and sizes. Due to the brittleness of the nonconductive oxides, the porous and broken parts of the contaminated sites might be caused by the machining process.

The results of microanalysis of the inclusions are listed in Table 1.

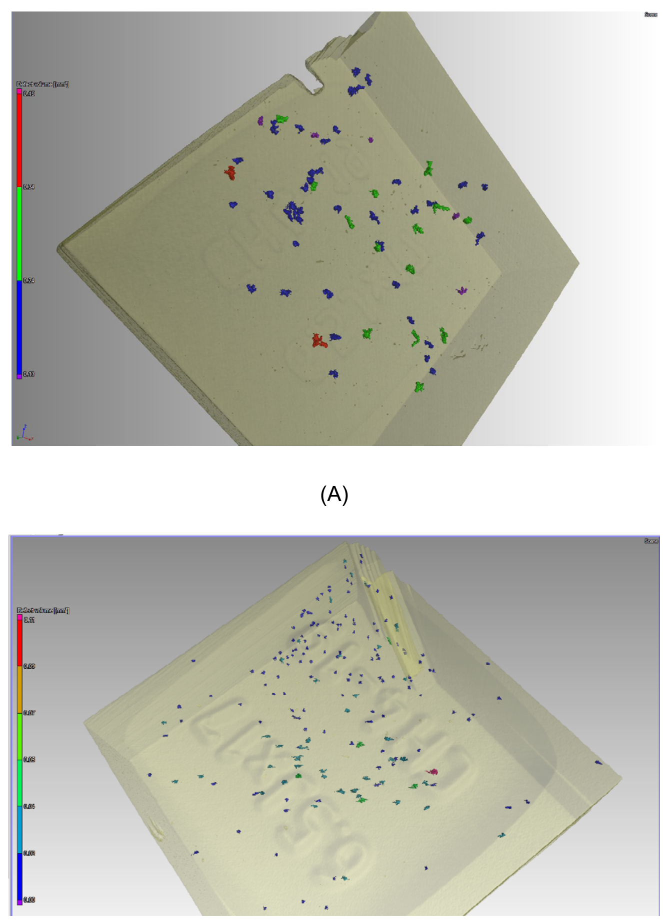
Table 1. The microanalysis results of inclusions in AlSi7Mg alloy

Site	Chemical element content (wt%)					
	Al	Si	Mg	O	C	Ti
1	11.33	0.67	45.65	41.50	–	0.51
2	51.46	2.54	1.12	38.82	3.21	1.01
3	32.77	0.83	23.46	34.30	1.01	0.87
4	54.74	1.06	0.51	40.70	1.54	1.10

3. Volumetric Content and Size Distribution of the Inclusions

The samples were inspected using X-ray tomography. All the samples were roughly in the same size of 40 × 40 × 15 mm. The X-ray tube was operated under the voltage of 240 kV and current of 170 mA. The resulting magnification on the detector was set to 3.6 times with the voxel size of 55.6 mm. The exposure time was set to 500 ms for each frame with averaging over three frames that result in one image. In total, 1,500 images with resolution of 2,014 × 2,024 pixels were recorded for each sample and used for reconstruction.

After the reconstruction process, a three-dimensional (3D) model of the sample was analyzed to find out the volumetric content and the size distribution of the inclusions. The transparent 3D models of the sample with color-marked inclusions are shown in Figure 3: the inclusions with density smaller than the bulk volume (Figure 3A) and the inclusions with density higher than the bulk volume of the sample (Figure 3B). For the analysis, the inclusions with sizes smaller or close to the size of the voxel were excluded in order to avoid uncertainties. The analysis showed that the average inclusions volumetric content (total volume of the inclusions divided by the bulk volume) is equal to 0.065%. This means



(A)

(B)

Figure 3. Reconstructed models from X-ray tomography showing locations of the inclusions in the bulk of the sample and the volumetric distribution: **(A)** inclusions with density smaller than the bulk volume (inclusion volume scale from 0.13 to 0.45 mm^3) and **(B)** inclusions with density higher than the bulk volume (inclusion volume scale from 0.0 to 0.11 mm^3).

these inclusions, even though not wanted, do not present any danger to structural stability or mechanical properties. The aluminum alloy car wheels, from which the samples were cut out, were intended for the high-end market. The aluminum alloy car wheels are machined from one side, and the machining pattern is exposed in the final product. Thus, the nonmetallic inclusions located on the machined surface of such a cast of the aluminum alloy car wheel qualify it for rejection.

4. Conclusions

The study of the nonmetallic inclusions in the AlSi7Mg alloy concluded that the most influential content of the inclusions comes from various oxides, mostly magnesium and aluminum oxides, and carbon contaminations. The nonconductive inclusions have size up to 1.5 mm, and they are highly irregular in shape and sizes. Some of the inclusions are porous or damaged during machining process. The X-ray tomography results allowed to identify the size and distribution of the nonmetallic inclusions inside the sample. Furthermore, systematic research should be performed to identify the source and the stage at which the contaminants are introduced, such as the remelting, degassing, salt cleaning, and casting processes.

Acknowledgments

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