Effect of Homogenization on Al-Fe-Si Centerline Segregation of Twin-Roll Cast Aluminum Alloy AA 8011

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Abstract

The effect of homogenization on centerline segregation has been studied in twin roll cast aluminum alloy AA 8011. It is observed that second phase particles generally form when the alloy contains high Fe and Si. During twin-roll casting process, beta phase of AlFeSi segregates at the centre of the strip in the thickness range of 10–15 μm. Such phase has a needle shape morphology that inversely affects the formability. Phase transformation from β-AlFeSi to α-AlFeSi is found to occur when homogenization is carried out at high temperature. During the phase transformation, the morphology of second phase particles also changes from needle to circular shape. Furthermore, it is also observed that the area fraction of second phase particles decreases with an increase in time and temperature. If homogenization temperature is increased, particle size growth is found to be dominant on the spread of intermetallic particles.

Keywords

Twin-roll cast • Centerline segregation • Homogenization • Morphology

Introduction

Aluminium is the second most commonly used material after Iron. A thin aluminum strip can be produced by two different processes: (i) Direct chill casting (ii) Continuous casting/ Twin roll casting. Bessember [1] gave an idea of twin roll casting while using two harden rolls and the small crucible of 9 kg capacity. Continuous strip casting for aluminum and its alloys was carried out by J. Hunter and W. Lauener in 1950 [2]. In twin roll casting process, molten metal was directly converted into 6–7 mm thick strip. Annealing and cold rolling operations were performed on this 6–7 mm thick strip to get the required thickness as well as mechanical properties [3, 4].

In Twin roll casting, centre-line segregation of second phase particles was most commonly found for high alloying content materials [5–11]. Ghosh [5] highlighted that physical movement of liquid and solid phases resulted into the macrosegregation due to the localization of microsegregation. Such second phase particles can move inward easily through the columnar zone. These particles agglomerate at the centre region of the strip cast alloy. If the foil undergoes further rolling, these particles come out from the matrix and create pin-holes. It occurs due to the mismatch in the mechanical properties of intermetallic particles with the base matrix [6]. The formation of pinholes must be prevented to reduce the moisture vapour and oxygen transmission rate as well as ultraviolet ray to produce an excellent quality of foil. Therefore, it is necessary to reduce centre-line segregation in order to enhance the downstream applications of foil for packaging materials.

In the present work, centre-line segregation of Al-Fe-Si compound is observed in high Fe and Si content 7 mm twin roll cast aluminum alloy AA 8011. Needle type morphology that inversely affects the formability is identified as the beta phase of AlFeSi compound. The second phase particles are also confirmed using Fe:Si ratio. Strip cast AA 8011 was homogenized at different temperatures and phase transformation from β-AlFeSi to α-AlFeSi was also evaluated. The objective of present communication is two folds as given below.

(i) To identify the phase transformation of AlFeSi compound concerning the morphology of the phases.
(ii) To determine the effect of homogenization on centerline segregation by considering the mean aspect ratio, mean intermetallic spacing and area fraction.

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C. Chesonis (ed.), *Light Metals 2019*, The Minerals, Metals & Materials Series,
https://doi.org/10.1007/978-3-030-05864-7_44

Experimental Procedure

High Fe and Si content strip cast aluminum alloy AA 8011 was used in the investigation. Strip cast aluminum alloy AA 8011 with 7 mm thickness was procured from Jawaharlal Nehru Aluminum Research Development and Design Centre (JNARDDC), Nagpur. The chemical composition of AA 8011 collected for characterization study is shown in Table 1. Before pouring the molten metal in between the rollers, holding furnace temperature and headbox temperatures were kept at 800 °C and 700 ± 5 °C respectively. The feed rate of molten metal that passed was kept 0.9 m/min.

Second phase particles inside the centre-line segregation were characterized using JEOL (JSM 7600F) Scanning Electron Microscope at IIT Gandhinagar. Elemental analysis was carried out using EDS attachment (Oxford, Model INCA Energy 250 EDS). The phases of second phase particles were identified using Fe to Si ratio. Homogenization was carried out using Nabertherm high-temperature furnace. Specimens were homogenized at 525, 550, 575 and 600 °C for 12 h respectively. The phase change from β-AlFeSi to α-AlFeSi was found to occur after 550 °C. The phase diagram for the equilibrium is shown in Fig. 1. Accordingly, homogenization was performed at different temperatures from 525 to 600 °C for different times (4, 8 and 24 h) respectively. Homogenization condition for all the specimens is shown in Fig. 2. Specimens were heated to a particular temperature in 2.5 h. The heating rate was kept slow to ensure the thermal equilibrium between the sample and furnace. Specimens were cooled inside the furnace from homogenization temperature to the room temperature. The cooling rate was assumed to be constant since it was not considered for further study. All the specimens were prepared for SEM analysis after homogenization. Elemental analysis was performed for the specimens. The second phase particles were analyzed by performing critical analysis, such as aspect ratio, the area fraction of the intermetallic compound, the mean distance between two intermetallic compounds.

Results and Discussion

Centerline segregation can be identified using optical microscopy. Scanning Electron Microscopy (SEM) was carried out to characterize the second phase particles that were difficult to observe using optical microscopy. Such particles were found to be segregated at the centre in the

Table 1 Chemical composition of AA 8011 (wt%)

Alloy	Si	Fe	Cu	Mn	Mg	Ti	Al
AA 8011	0.6	0.62	0.01	0.004	0.001	0.009	98.74

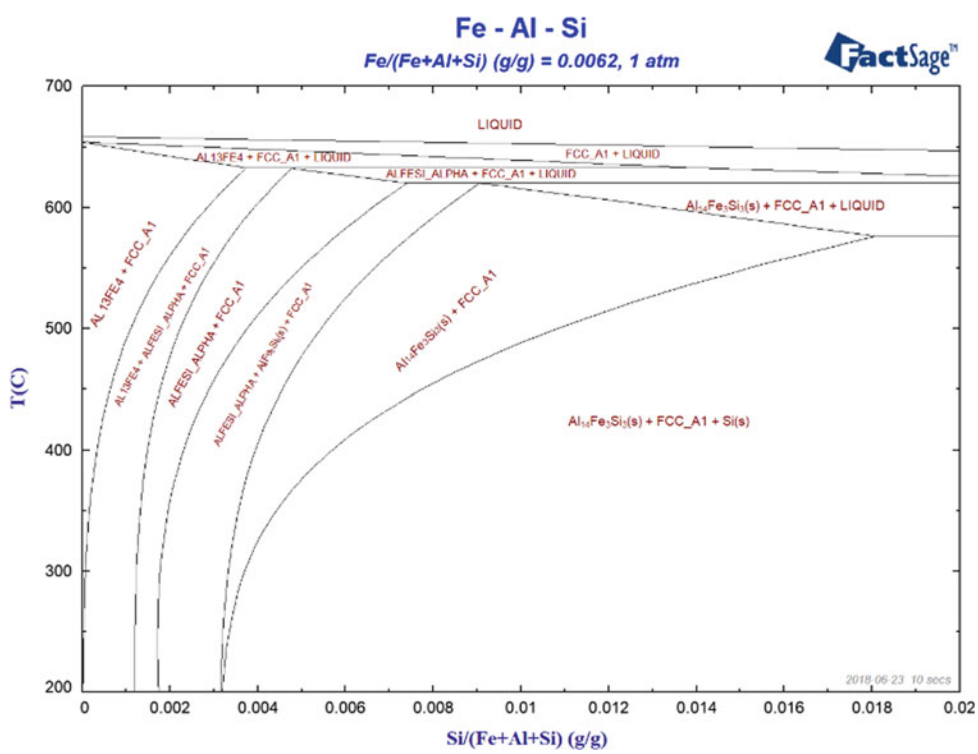


Fig. 1 Al-Fe-Si ternary phase diagram (for Fe = 0.62 wt%) [FactSage]

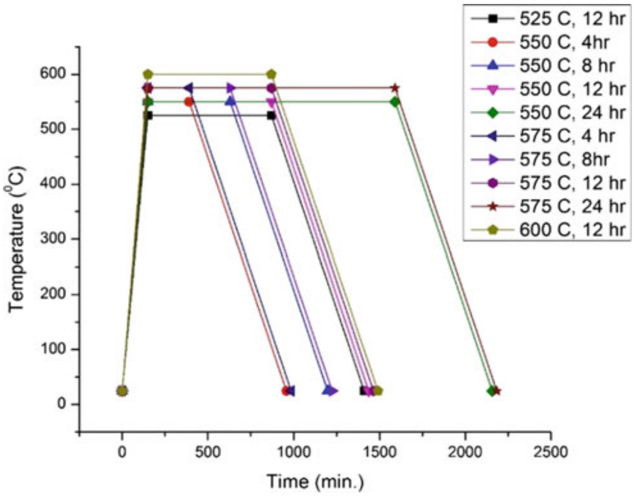


Fig. 2 Homogenization of strip cast AA 8011

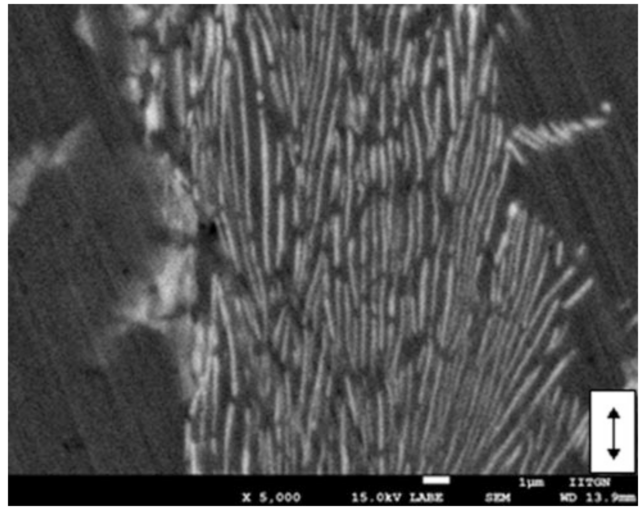


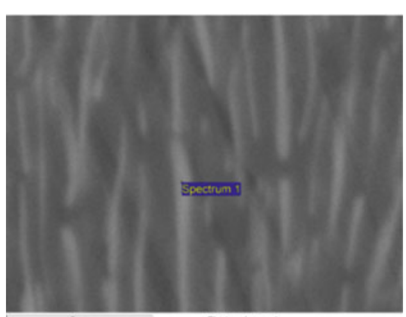
Fig. 3 Centerline segregation in strip cast AA 8011

range of 10–15 µm thickness in 7 mm thick strip. Second phase particles having sharp needle type morphology were found in centerline segregation as shown in Fig. 3. These particles were also much closure to each other. Elemental analysis was performed on one of the needle type intermetallic compounds as shown in Fig. 4. It was found that the Fe:Si ratio (wt%) was nearly 2:1. The atomic ratio of Fe:Si was quite close to unity. The chemical composition of Al_5FeSi /$Al_9Fe_2Si_2$ was reported for β Al-Fe-Si phase [3, 8, 12]. Therefore, β-AlFeSi phase was confirmed based on Fe:Si ratio and with the morphology of second phase particles.

The second phase particles inside the centerline segregation after different homogenization conditions are shown in Fig. 5. Few particles were converted into an irregular shape and remaining all particles were still found in needle type morphology after homogenization at 550 °C. Second phase particles were found to be converted into circular shape after homogenization at 575 °C. Chemical composition was identified for different morphology. Fe:Si ratio was found to vary concerning morphology as shown in Table 2. Elemental analysis was performed for both needle type and irregular shape particles after homogenization at 550 °C for 12 h. Fe:Si ratio for the needle type intermetallic compound was nearly 2:1 and this was quite close to unity in wt% and atomic% respectively. Therefore, β phase could be confirmed for the needle type particles. The ratio for the irregular intermetallic compound was measured nearly 4:1 and 2:1 in wt% and atomic% respectively. Similar Fe:Si ratio was also found for α phase of Al-Fe-Si as it formed Al_8Fe_2Si/$Al_{12}Fe_3Si_2$ intermetallic compound [12]. Therefore, α-AlFeSi could be confirmed for the irregular shaped second phase particle. However, such phase transformation was observed for very few particles. The similar ratio was also observed for the circular particles after homogenization at 575 °C. Therefore, the phase transformation from β-AlFeSi to α-AlFeSi was confirmed based on morphology and Fe:Si ratio. Aspect ratio, the mean intermetallic spacing and area fraction of second phase particles are also shown in Table 2.

Phase transformation highly depends on temperature as compared to time. The mean aspect ratio, intermetallic spacing and area fraction of second phase particles for each homogenization condition are shown in Fig. 6a–c respectively. It can be concluded that a significant phase transformation has taken place at 575 °C. The maximum difference

Fig. 4 Elemental analysis of needle type second phase particle



Element	Wt %	Atomic%
Al	85.90	90.41
Si	4.83	4.88
Fe	9.27	4.71

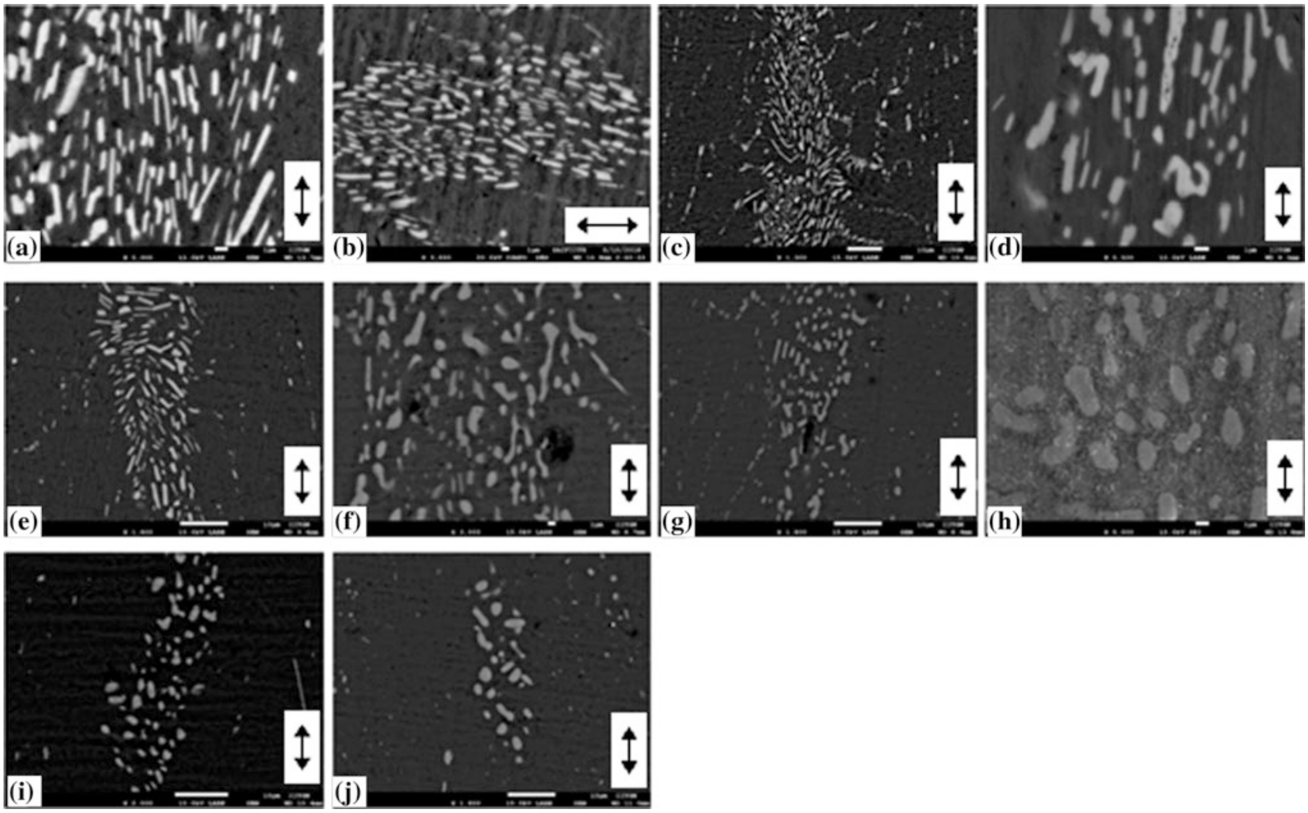


Fig. 5 Second phase particles inside centerline segregation after homogenization at 525 °C for 12 h (**a**), 550 °C for 4 h (**b**), 550 °C for 8 h (**c**), 550 °C for 12 h (**d**), 550 °C for 24 h (**e**), 575 °C for 4 h (**f**), 575 °C for 8 h (**g**), 575 °C for 12 h (**h**), 575 °C for 24 h (**i**) and 600 °C for 12 h (**j**)

Table 2 Effect of different homogenization condition on centerline segregation

Sr.	Homogenization condition	Morphology of second phase particle	Fe:Si ratio		Mean aspect ratio	Mean intermetallic spacing (μm)	Area fraction (%)
			wt %	Atomic %			
1	As received	Needle	1.92	0.97	15.12	0.36	32.48
2	525 °C for 12 h	Needle	1.98	0.99	6.184	1.24	20.57
3	550 °C for 8 h	Needle	1.77	0.89	3.82	1.21	19.54
4	550 °C for 12 h	Needle	1.95	0.98	3.13	1.45	18.77
		Irregular	4.13	2.08			
5	550 °C for 24 h	Needle	1.83	0.92	3.47	1.79	16.59
6	575 °C for 4 h	Circular	3.45	1.73	2.43	2.73	19.33
7	575 °C for 8 h	Circular	3.57	1.8	1.68	2.15	17.82
8	575 °C for 12 h	Circular	3.33	1.67	1.57	2.72	15.7
9	575 °C for 24 h	Circular	3.57	1.8	1.37	2.87	12.4
10	600 °C for 12 h	Circular	3.2	1.61	~1	3.58	13.7

in aspect ratio was found to occur in between 4 and 8 h homogenization period but the same was not observed after 8 h. Therefore, homogenization at 575 °C for 8 h could be considered as the optimum homogenization parameter for the twin roll casting. The second phase particles spread at higher temperature and these increase with an increase in time. Therefore, the mean intermetallic spacing was also increased concerning both time and temperature. The intermetallic compounds per unit area were reduced due to the dispersion of intermetallic particles. Therefore, area fraction was

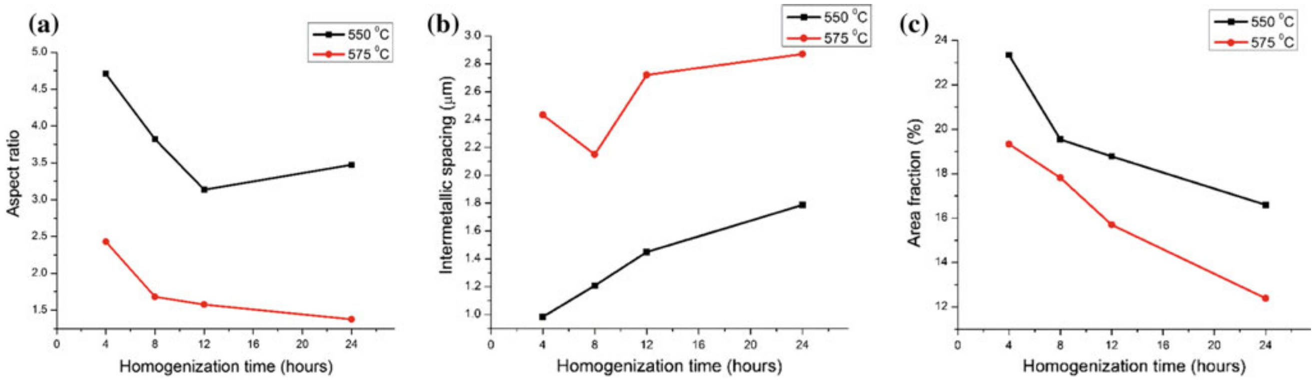


Fig. 6 Aspect ratio (**a**), mean intermetallic spacing (**b**) and area fraction (**c**) of second phase particles for each homogenization condition

decreased with increase in time. As the homogenization was switched to a higher temperature, the growth in size of intermetallic particles was found to be more dominant than the spread. Therefore, though the mean intermetallic spacing was increasing, more area fraction was observed for homogenization at 575 °C for 4 and 8 h specimen as compared to homogenization at 550 °C for 24 h.

Conclusion

1. Second phase particles of Al-Fe-Si compound agglomerate inside the centerline segregation. Needle type second phase particles are in beta phase whereas circular particles are in alpha phase. Phase transformation highly depends on temperature as compared to time. Significant phase transformation from β-AlFeSi to α-AlFeSi is observed when homogenized at 575 °C. Accordingly, the morphology of intermetallic particles also changes from needle to circular shape.
2. The spread of intermetallic particles along with particles size growth takes place at high-temperature homogenization. The area fraction of second phase particles reduces with increase in time. However, if the homogenization is switched to high temperature, it is observed that the growth in particle size is more dominant than the spread.

Acknowledgements Authors wish to acknowledge Mr. RN Chouhan and JNARDDC Nagpur for providing Twin roll cast AA 8011. Authors also wish to acknowledge Mr. Amit Singh (IIT Gandhinagar) and SAIF, IIT Bombay for performing SEM experiment. The support of IIT Gandhinagar is highly acknowledged.

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