УДК 669.018.23:620.18

M. V. Koshelev, A. G. Prigunova, A. G. Vernidub

Physical and Technological Institute of Metals and Alloys of the NASU, Kyiv

Email: silica-lum@ukr.net

THE EFFECTS OF MN ADDITION FOR THE PREDICTION OF THE THIXOFORMABILITY OF FE-CONTAINING AL-SI BASED ALLOYS

Semi-solid metal processing has nowadays been established as an advanced technology in the manufacturing of engineering components. This process relies on the thixotropic behavior of alloys which have a spheroidal rather than a dendritic microstructure in the semisolid state [1]. With the development of research and practice of semi-solid forming technology, some criteria of alloy selection have been proposed on the basis of thermodynamic modeling, DTA/DSC experiments and the evaluation of liquid fraction vs. temperature curves [2, 3]. The numerical values of the critical points from these curves (solidification temperature range, liquid fraction at eutectic temperature, working window temperature and fraction liquid sensitivity) can help optimize the chemical composition of the alloys produced for semi-solid forming technology. In Fe-containing Al-Si based casting alloys manganese is the most common alloying additive which is capable of changing the morphology of the iron-rich phase from platelets to a more compact form or to globules, depending on the Mn/Fe weight ratio and the cooling rate [4, 5]. Recently, researches have been focused on changing the morphology of the Fe-containing intermetallic compounds. In this preliminary work, DTA experiments was used to study the effects of Mn addition for the prediction of the thixoformability of Fe-containing Al-Si based alloys.

Three types of hypoeutectic Al–Fe–Si alloys with Mn addition were prepared from high-purity aluminum, mono crystalline silicon, pure iron and manganese to avoid any contamination. The chemical compositions of the produced ingots are listed in Table 1.

Table 1. Detailed chemical composition of experimental alloys in mass %

Alloy No.	Elements (wt. %)			Mn/Fe weight ratio
	Si	Fe	Mn	
1	8,51	1,16	0.11	0.1
2	6,76	1,16	0,3	0,3
3	6,09	1,12	0,69	0,7

The samples for DTA studies were cut from ingots in the form of disks weighing about 200 mg. The DTA sample was heated to 730 °C and then cooled to room temperature at the rate (5°C/min). Microstructure analysis was done on polished and deep-etched samples after DSC tests using a MIM-8 optical microscope. The micrographs were taken using a digital camera DCM–510 that was attached to the microscope.

DTA trace curves obtained during solidification and the variation of liquid fraction vs. temperature for all studied alloys are presented in Figure 1.

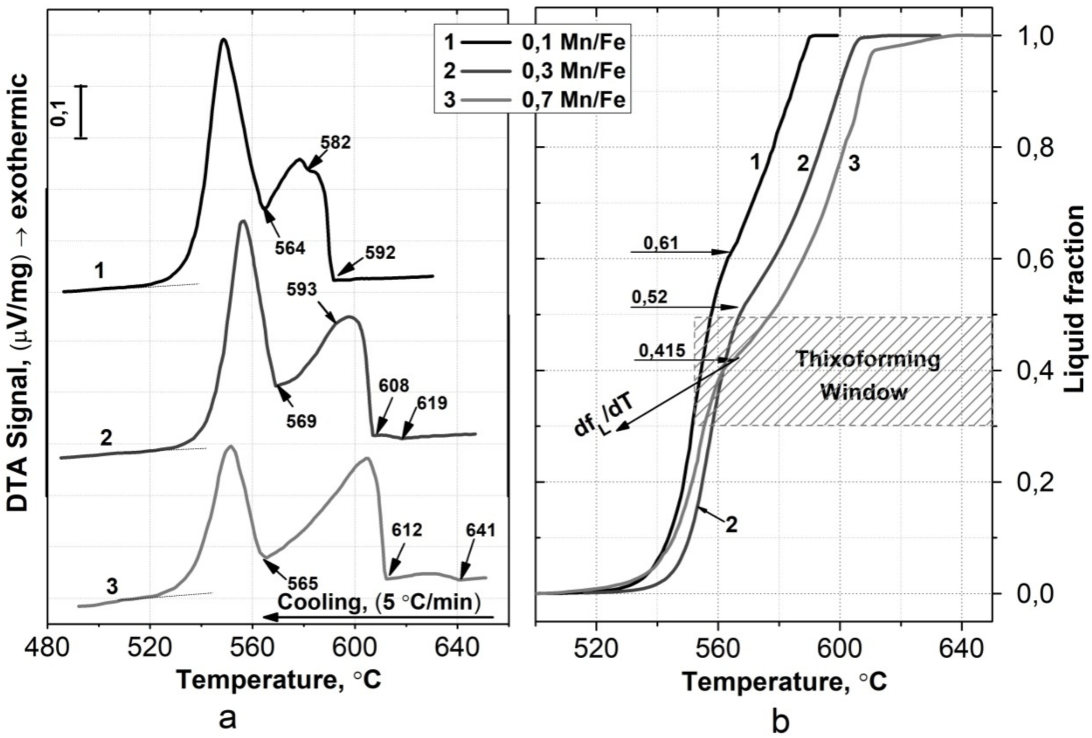


Fig. 1 – DTA curves (a) and variation of liquid fraction vs. temperature (b) for three types of investigated alloys

On DTA trace curves (Figure 1 a), it can be clearly observed the presence of two main peaks for all three alloys which can be related to the solid-liquid transformation, and the eutectoid transformation (the latter around 565°C in all cases). Peaks at higher temperature include reaction: L + Alα and L + Alα +Al_5FeSi (Figure 1 a, alloy 1,2), second peak appears in the curves, giving the temperatures for the start of β – Ai_5FeSi phase precipitation around 582 °C (for alloy 1) and around 593°C (for alloy 2). With increasing Mn/Fe ratio from 0.3 to 0.7 (Figure 1 a, alloy 2, 3) on cooling from liquid, it is expected the formation of α - ($Al_{15}(Mn,Fe)_3Si_2$ phase (to be referred as α* - AlFeMnSi in this work) directly from the liquid as primary phase starts at the temperatures about 619 °C and 641 °C respectively.

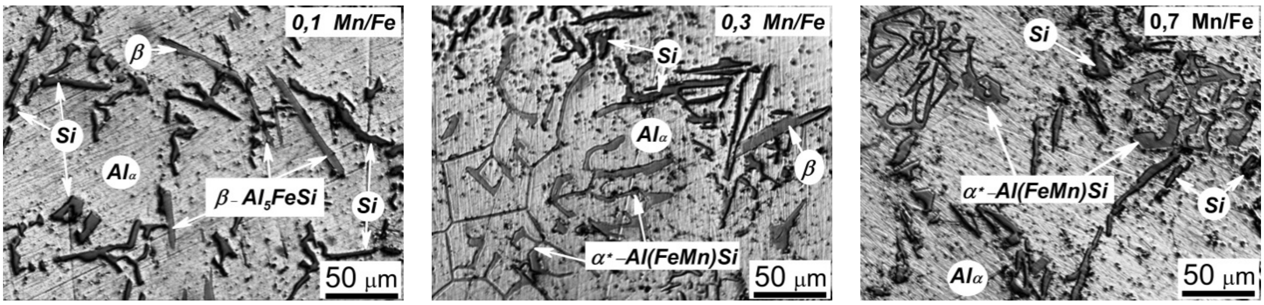
Considering the fraction liquid vs temperature curves (Figure 1 b) it can be seen that with increasing on Mn/Fe rations in the investigated alloys the solidification temperature interval increased and the eutectic amount significantly decreased. Some parameters of the solidification process that are important in predicting semisolid behavior (or thixoformability) are presented in Table 2.

Table 2. Parameters estimated from the liquid fraction vs. temperature curves

Alloy No.	Mn/Fe ratio	Solidification Interval ΔT(°C)	Amount eutectic (%)	Working window temperature, $\Delta T^{0.3/0.5}$ (°C)	Temperature sensitivity, $(df_L/dT)_{fL=0.4}$ (°C^{-1})
1	0,1	28	61,16	6.7	0,032
2	0,3	50	52,35	9,2	0,024
3	0,7	76	41,52	21,8	0,01

In particular, the alloy with 0.1 Mn/Fe ratio (Table 2), due to a narrow thixoforming working window (around 7°C) and a high temperature sensitivity of liquid fraction with temperature within this range (0.032°C^{-1} at df_L/dT_{fL}=0.4) indicate low thixoformability. Therefore, a smaller fraction liquid sensitivity at semisolid processing temperature indicates better thixoformability. With increasing Mn/Fe ratio the fraction liquid sensitivity decreases from 0.032 (alloy 1) to 0.010 (alloy 3).

The micrographs of the samples with different Mn/Fe ratios solidified after DTA test at low cooling rate in ceramic crucible are presented in Figure 2.



a b c

Fig. 2 – Optical micrographs of specimens with different Mn/Fe weight ratios (a) - 0.1 Mn/Fe, (b) - 0.3 Mn/Fe, (c) - 0.7 Mn/Fe

The microstructure of all three alloys (Figure 2) exhibited a typical hypoeutectic solidification structure consisting of Alα - solid solution (white in contrast), eutectic silicon Si (black in contrast) and iron-rich intermetallic particles (grey in contrast). There is a significant difference in the morphology of the iron-containing phases formed in the metal matrix when the Mn/Fe ratio was increased. Thus, small additions of Mn, when the Mn/Fe = 0.1 (Figure 2 a) the β-Al_5FeSi compound tends to crystallize in the form of extremely large needle-like particles. With increasing Mn/Fe ratio from 0.3 (Figure 2 b) to 0.7 (Figure 2 c) could promote the formation of a more compact α*- Al(FeMn)Si phase and reduce the formation of harmful β - Ai_5FeSi phase. The primary α* - Al(Fe,Mn)Si particles exhibit a spherical more compact morphology (Figure 2 c) when they are small, and they may develop into more complex morphologies with an increase in their sizes.

The effects of Mn addition for the prediction of the thixoformability of Fe-containing Al-Si based alloys have been investigated by DTA and optical microscopy. The experimental findings clearly demonstrated that altered Mn/Fe ratios (up to 0.7) in the studied alloys can reduce temperature sensitivity of liquid fraction ($df_L/dT_{0.3–0.5}$) and enlarge to a large extent the solidification temperature interval and the temperature window between 30% and 50% fraction liquid. Moreover, with increasing Mn/Fe ratio from 0.3 to 0.7 plate-like β-Al_5FeSi phase transforms to a more compact α* - Al(FeMn)Si phase which are more favorable for the semi-solid forming technology.

References

1. H.V. Atkinson, Alloys for Semi-Solid Processing, Solid State Phenomena Vols. 192-193 (2013) pp 16-27.

2. E.J Zoqui, D.M., Benati,C.T.W..Proni, L.V. Torres. Thermodynamic evaluation of the thixoformability of Al–Si alloys. Calphad (2016), 52, pp. 98–109.

3. D. Liu, H.V. Atkinson, H. Jones, Thermodynamic prediction of thixoformability in alloys based on the Al-Si-Cu and Al- Si-Cu-Mg systems, Acta Materialia 53 (2005) 3807-3819.

4. Balitchev, E.; Jantzen, T.; Hurtado, I.; Neuschütz, D. Thermodynamic assessment of the quaternary system Al–Fe–Mn–Si in the Al-rich corner. Calphad 2003, 27, 275–278.

5. S.G. Shabestari, The Effect of Iron and Manganese on the Formation of Intermetallic Compounds in Aluminum-Silicon Alloys, Materials Science and Engineering A, Vol. 383, 2004, pp. 289-298.