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**THE INFLUENCE MANGANESE ON THE PREDICTION
THIXOFORMABILITY OF FE-CONTAINING AL-SI BASED ALLOYS**

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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 [4-6]. Recently, researches have been focused on changing the morphology of the Fe-containing intermetallic compounds. In this investigation, DTA experiments were 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.

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).

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

Phase identification of the alloys was conducted by X-ray diffraction by a diffraction (XRD) using a DRON-3M diffractometer in Cu-K α radiation at 40 kV and 100 mA. The measurements were performed by angle range of 2 θ : 15°–105°, and the diffraction peaks were labeled on the database of Joint Committee Powder Diffraction Standards. 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.

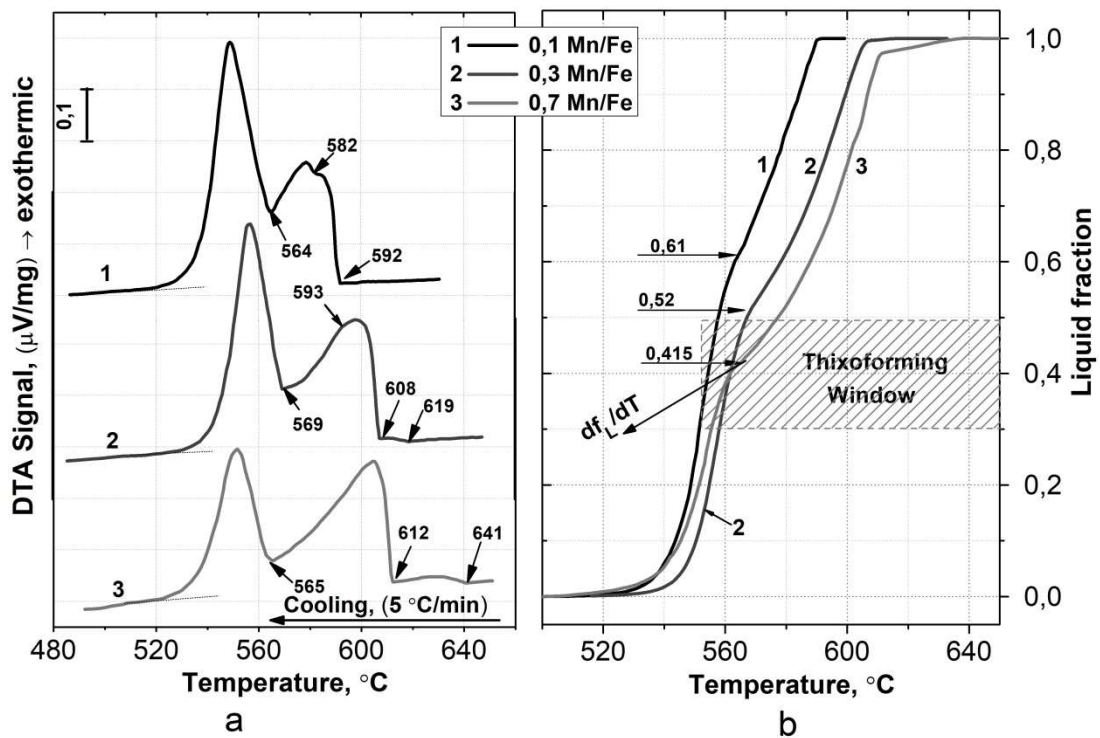


Fig. 1. DTA curves (a) and variation of liquid fraction vs temperature (b) for three types of investigated alloys

On DTA trace curves (Figure 1, a) clearly show the presence of two main peaks for all three alloys, which are associated with transformations in the liquid-solid state. From temperatures of 592 °C (Figure 1, a, alloy 1), 608 °C (Figure 1, a, alloy 2) and 612 °C (Figure 1, a, alloy 3), primary crystals of aluminum solid solution begin to separate according to the reaction: $L \rightarrow Al\alpha$. The next is the eutectic transformation associated with the formation of the β -Al₅FeSi phase: $L \rightarrow Al\alpha + \beta$ -Al₅FeSi, which occurs at a temperature of 582 °C in alloy 1 and 593 °C in alloy 2. With an increase in the Mn/Fe ratio from 0.3 to 0.7 (Figure 1, a, alloys 2, 3), the primary phase α -(Al₁₅(Mn,Fe)₃Si₂) (in this work it will be denoted as α^* -AlFeMnSi) is separated directly from the melt at temperatures of about 619 °C (alloy 2) and 641 °C (alloy 3), respectively.

Considering the fraction liquid vs temperature curves (Figure 1, b) it can be seen that with increasing on Mn/Fe ratios 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.

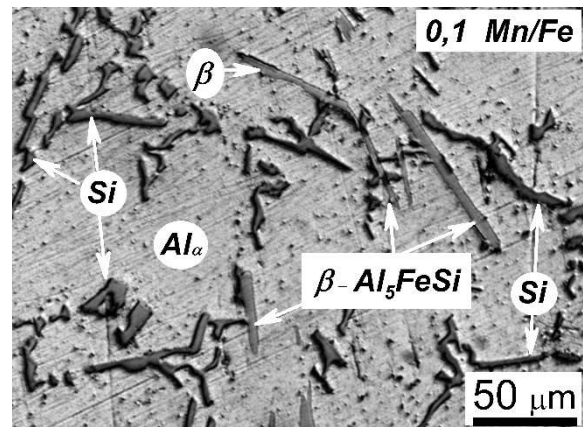
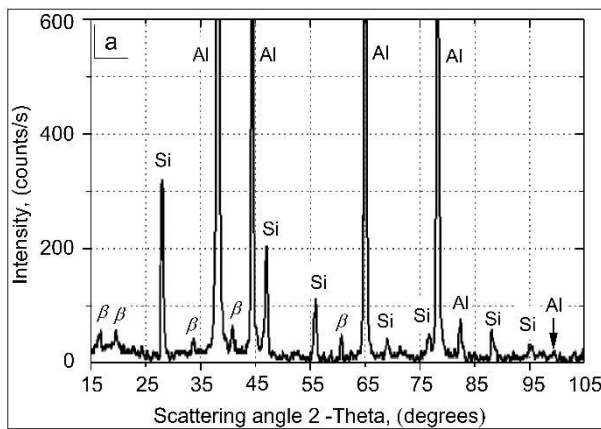
Table 2 – Parameters estimated from the liquid fraction vs. temperature curves

Alloy No	Mn/Fe ratio	Solidification interval $\Delta T(^{\circ}C)$	Amount eutectic (%)	Working window temperature, $\Delta T^{0.3/0.5} (^{\circ}C)$	Temperature sensitivity, $(df_L/dT)_{f_L=0.4} (^{\circ}C^{-1})$
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	0.010

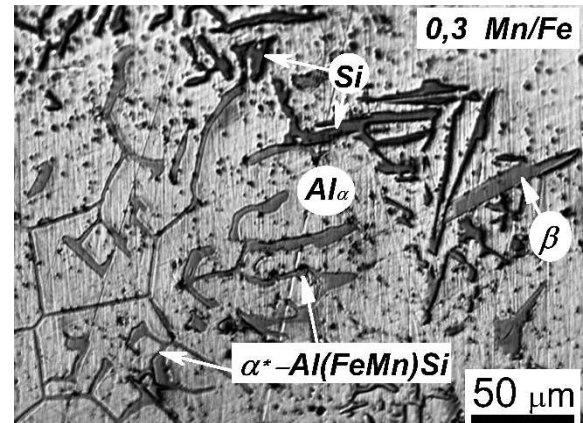
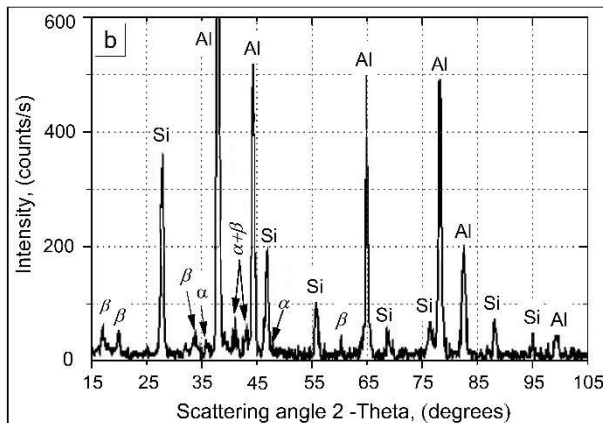
In particular, the alloy with 0.1 Mn/Fe ratio (Table 2), due to a narrow thixoforming working window (around 7 °C) and a high temperature sensitivity of liquid fraction with temperature within this range ($0.032^{\circ}C^{-1}$ at $df_L/dT_{f_L=0.4}$) indicate low thixoformability. Therefore, a smaller 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 XRD analysis and metallographic examination 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.

The microstructure of all three alloys (Figure 2) exhibited a typical hypoeutectic solidification structure consisting of Al_α – 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 - Al_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.



a



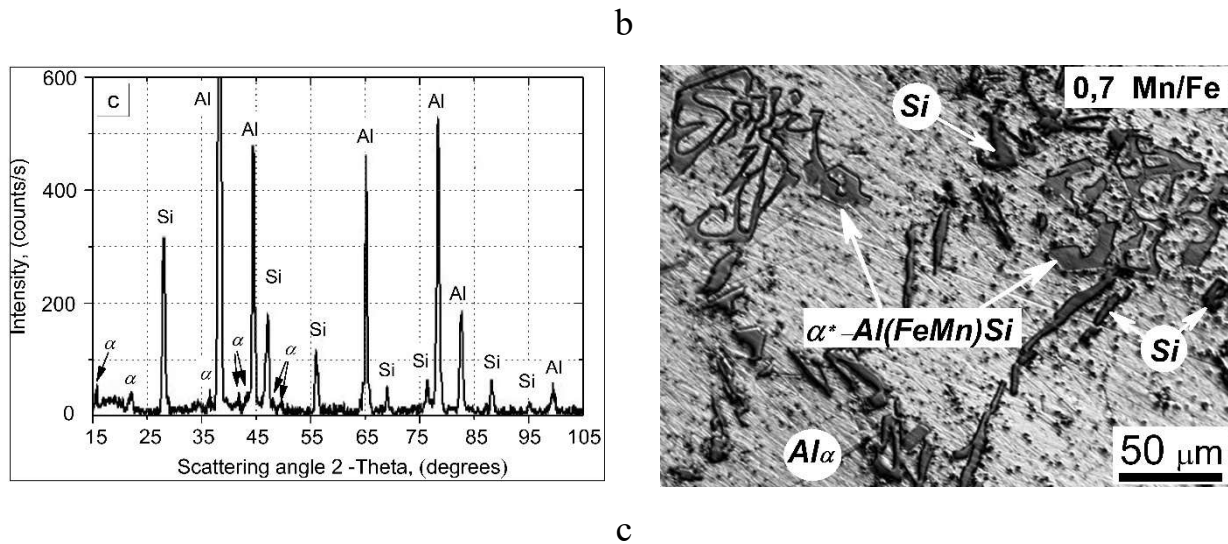


Fig. 2. XRD patterns and optical micrographs of specimens with different Mn/Fe weight ratios in the investigated alloys: a – 0.1 Mn/Fe, b – 0.3 Mn/Fe, c – 0.7 Mn/Fe

From a comparison of the X-ray diffraction patterns of samples with different percentages of manganese addition (Figure 2) it becomes obvious that the mechanism of the influence of manganese on the growth forms of iron-containing phases consists in a change in the nature of phase transformations during solidification, as a result of which, instead of the needle-shaped intermetallic β -FeSiAl₅ with a monoclinic lattice, a branched hexagonal phase [4], which in the literature is designated as α -(Fe,Mn)₃Si₂Al₁₅.

The effects of Mn addition for the prediction of the thixoformability of Fe-containing Al-Si based alloys have been investigated by DTA, XRD 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 -Al₅FeSi 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. Prigunova A.G. Mechanism of neutralization of harmful influence of iron in silumins by microadditives of manganese and chromium // *Metallophysics and latest technologies*. - 1998. - Vol.20. - No.12. - P. 25-32.
5. 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.
6. 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.

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**STUDY OF JET FOUNTAINING AND LIQUID STEEL SPREADING DURING
THE INITIAL STAGE OF LARGE HORIZONTAL INGOT CASTING**

The search for ways to improve large ingot casting technology to enhance quality and reduce production costs is ongoing. Horizontal ingot casting (LH-ingots) is an effective method for producing high-quality billets for large slabs, thick sheets, and other heavy products requiring high isotropy of properties [1, 2]. The horizontal position of the ingot, when its height is significantly less than its length and width, enables unidirectional solidification of the metal from bottom to top. Consequently, such ingots exhibit increased physical and chemical homogeneity compared to products obtained by traditional casting methods. Notably, shrinkage defects and signs of liquitation are absent in the central part of the ingot, which are common in large ingots of traditional design.

Some enterprises developed and implemented the technology for casting large-scale LH ingots with unidirectional solidification for heavy plates in the 1980s and