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An Application for Infrared Camera in Analyzing of the Solidification Process of Al-Si Alloy

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Abstract

The paper presents the results of the crystallization process of silumin by the TDA thermographic method and the results of the cast microstructure obtained in the sampler TDA-10, that was cooling down in ambient air. The study was conducted for silumin AlSi11 unmodified. The work demonstrated that the use of thermal imaging camera allows for the measurement and recording the solidification process of silumin. Thermal curve was registered with the infrared camera and derivative curve that was calculated on the base of thermal curve have both a very similar shape to adequate them TDA curves obtained from measurements using a thermocouple. Test results by TDA thermographic method enable quantitative analysis of the kinetics of the cooling and solidification process of neareutectic silumin.

Keywords: Innovative Foundry Technologies and Materials, Thermography, TDA, Silumin, Microstructure

1. Introduction

This work is a continuation of research into the improvement of thermal and derivative analysis (TDA) in research the solidification process of metals and alloys. The paper presents the possibility of implementing TDA with a thermal imaging camera. The theoretical basis TDA methods for metals and alloys including Al-Si alloys developed S. Jura [1]. At the turn of the last few years, this method is still developing. New types of probes have been developed, new basic software of the methods as well as new control algorithms. This expands its application to the study of new types of metal materials [2-6].

According to them, thermal and derivative analysis is carried out by an apparatus Crystaldigraph and a ceramic probe (e.g. ATD-10) with the thermocouple type K or S placed in the middle of the heat of sample area. In the TDA method are recorded two curves: cooling $t = f(\tau)$ and crystallization $t' = dt/d\tau = f'(\tau)$. Crystallization phases during cooling of the melt causes specific for sample alloy stops of temperature on thermal curve reflected clear thermal effects (peaks and humps) on the derivative curve. Interpretation of shape and characteristic point values of the two TDA curves allows the analysis of the solidification process and evaluate the quality of prepared, the liquid alloy casting.

Temperature measurement in the TDA method uses a thermocouple that is the basis for the calculation and registration of the curves. Its operation is based on the phenomena of occurrence of the point of connection of two different metals of the electromotive force, the magnitude of which depends on the temperature of the connector. This phenomenon has been noted and explained in the nineteenth century by Seebeck, Peltier and Thomson [7].

Currently, thermography is a very fast growing method allowing to track various processes that cause fixed and variable temperature field. The essence of the method is the assumption that all of the solids, liquids and gases whose temperature is higher than absolute zero (0 K) emit radiation with an energy dependent on temperature and wavelength of radiation [8].

Infrared thermography involved in detection, registration, processing and visualization of invisible infrared light (heat) emitted by the tested object. An essential element of modern infrared cameras is microbolometer infrared detector. Converting a photon energy of infrared radiation into an electrical signal. The value of the received signal depends directly on the temperature of the object, lens type, size and resolution matrix detector. These modern cameras work with a high resolution matrix of and an advanced methods of reading infrared amplification, the current-voltage conversion (IU) and a correction of heterogeneity signal. These features enable them recording the high-resolution temperature field at several tens mK and frequency measurement order of 10^2 Hz [9].

2. Experimental

The research was conducted on a station, which schematically was shown in Figure 1. The station is equipped with a resistive melting furnace, Crystaldigraph PC (U/f converter + software) manufactured by Z-TECH, infrared camera PI OPTRIS 160, the probe ATD-10 shown in Figure 2, optionally equipped with a quartz glass piece and a computer PC to control and record obtained results. Microstructure of the samples was performed using a Nikon microscope MA200.

Research solidification process of the silumin was carried out simultaneously by Crystaldigraph in the sampler ATD-10 and the infrared camera. During the tests the temperature measurement and recording of solidifying the sample of silumin performed using thermocouple S and by observation of the free surface of the metal sample - in the first variant and with use the quartz piece - in the second variant. The tests were performed for AlSi11 alloy, which chemical composition is shown in Table 1.

Table 1.
Chemical composition of AlSi11 alloy

Alloy	Chemical composition, %								
	Si	Mg	Cu	Mn	Fe	Ti	P	B	Sr
AlSi11	12.84	0.516	0.061	0.037	0.173	0.016	0.001	0.0062	0.0001

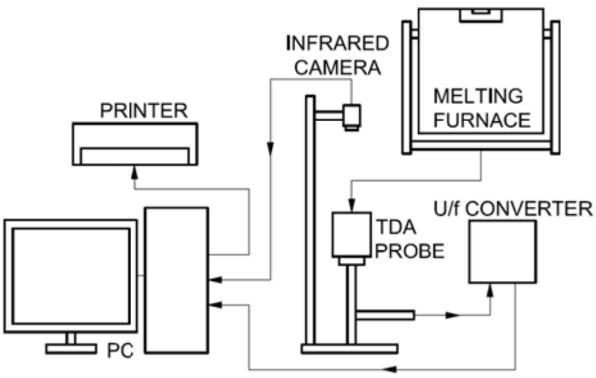


Fig. 1. Scheme of research station

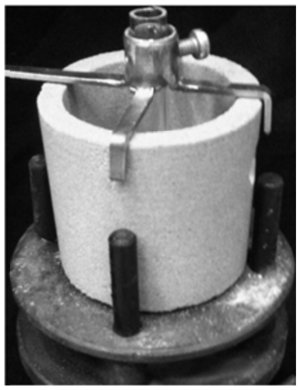
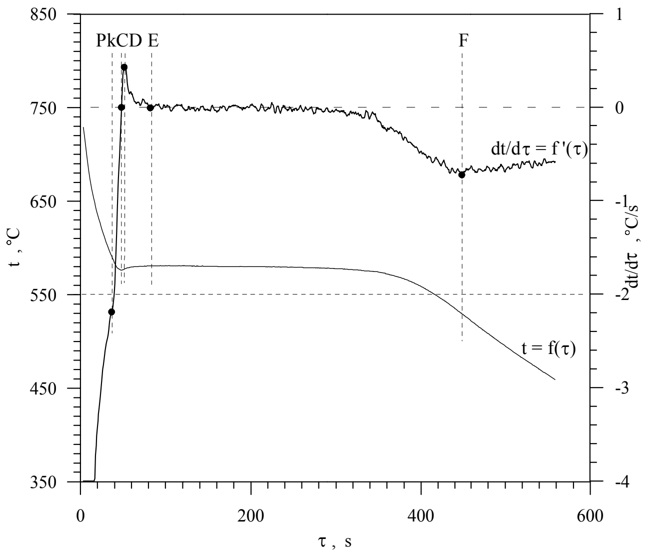


Fig. 2. View of ATD-10 probe with quartz glass piece

3. Results

Foundry technical alloy AlSi11 is with neareutectic Al-Si alloy. In its composition is dominated by two elements, aluminum and silicon, wherein the silicon content may range from about 10÷13%. The microstructure of this silumin group presents in the dominant amounts of eutectic $\alpha + \beta$ (Al + Si). The amount depends on the speed of growth, temperature gradient and chemical composition, which define the size and shape of the coupled growth zone. In Figure 3 was shown a representative TDA curves and characteristic values of temperature and cooling rate of the alloy obtained from measuring temperature by thermocouple in probe ATD-10. Figures 4 and 5 show properly thermographic image (Fig. 4) during the analysis of silumin solidification in the ATD-10 probe and the TDA curves achieved with use of the infrared camera (Fig. 5). The microstructure of the obtained silumin samples is shown in Figure 6.



	Pk	C	D	E	F
t, °C	588	576	577	580	534
dt/dτ, °C/s	-2.14	0	0.45	0	-0.71

Fig. 3. TDA curves and specific point values of solidification process achieved by TDA method

The study of solidification process by TDA, the chemical composition analysis and microstructure of silumin observations demonstrate that silumin solidification starts at a point Pk of nucleation of silicon. Its thermal effect is reflected in the form of inflection derivative curve at tPk = 588-590°C. In the micro-regions surrounding separated silicon crystals liquid supersaturates the aluminum, resulting in crystallization of small dendrites of aluminum.

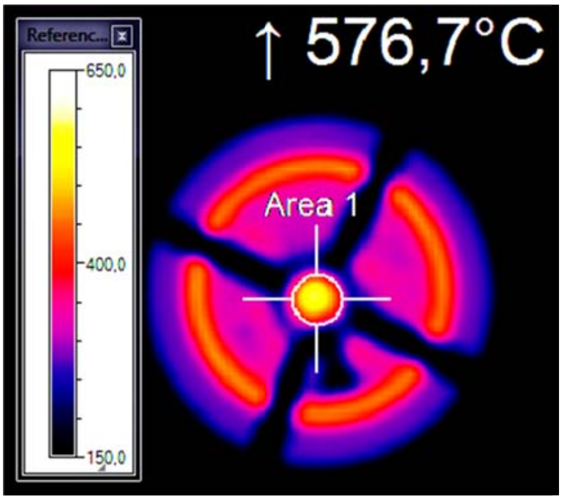
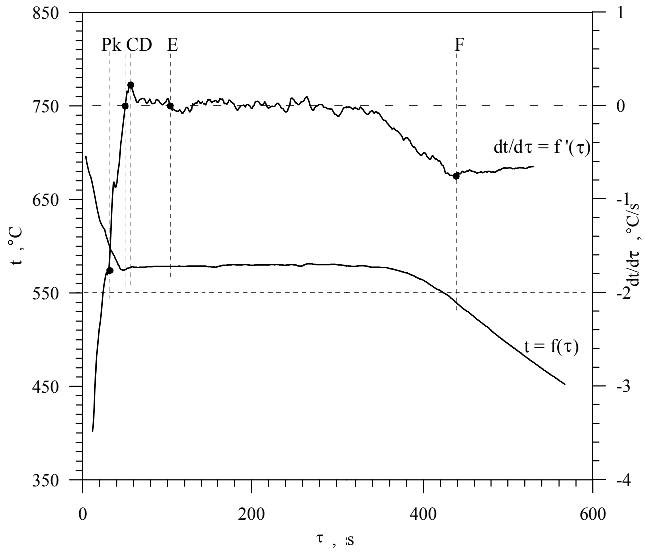


Fig. 4. Thermographic image of silumin during the solidification analysis with the reference bar

After supercooling the liquid below the transition eutectic temperature tC = 575-576°C, silumin enter into a coupled zone of growth of eutectic and in the range CDEF irregular eutectic lamellar α + β (Al + Si) crystallizes. This process is stabilized at tE = 579÷580°C. Crystallization of silumin ends at tF = 533-534°C.

On the derivative curves (dt/dτ = f '(τ)) the test results using TDA (fig. 3) and thermographic method (Fig. 5) have combined heat effects of phases crystallizing preeutectically and eutectic mixture (Al + Si).



	Pk	C	D	E	F
t, °C	590	575	578	579	533
dt/dτ, °C/s	-1.84	0	0.24	0	-0.68

Fig. 5. TDA curves and specific point values of solidification process achieved by thermographic method

A comparison of the characteristic points temperature values of thermal curves shows that there are small differences in the range of 1÷2°C. Moreover the thermographic method demonstrates taht the kinetics of the initial maximum thermal effect is equal to $(dt/d\tau)_D$ = 0.24°C/s. It is less than in the TDA method $(dt/d\tau)_D$ = 0.45°C/s, but the effect is present by a longer period. End of silumin crystallization is identified in both methods similar cooling rate value $(dt/d\tau)_F$ = (-0,71÷-0.68) °C/s.

Figure 6 illustrates a representative microstructure of a test silumin in temperature measurement zone (Fig. 2 and 3) obtained in the sampler TDA (Fig. 2) cooling down naturally at ambient temperature. The research shows that in the microstructure of the cast are grains of Al + Si eutectic (α+β) and probably crystallized preeutectically, single longwall (20÷50μm) silicon precipitates (β) and dendritic separation of aluminum (α). The research shows that the rate of liquid silumin cooling about 3°C/s and average cooling rate of the alloy solidification temperature range is equal 0.14 °C/s. These conditions can be cause that in silumin with eutectic content of silicon, crystallize not only eutectic grains but also the primary crystals which are shaped before eutectic mixture.

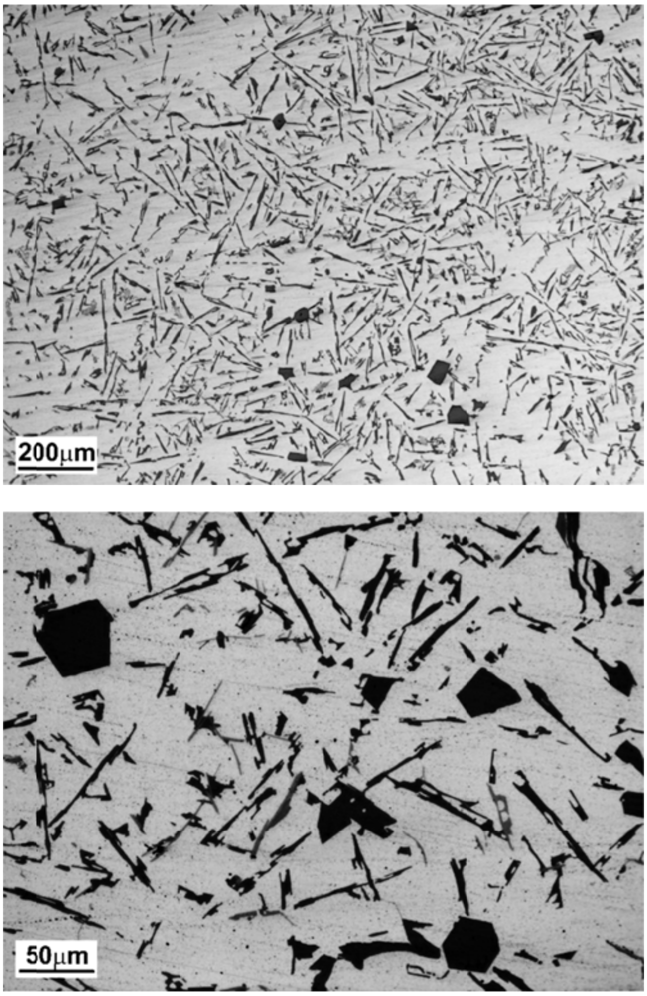


Fig. 6. Microstructure of AlSi11 alloy. Phases: β(Si), α(Al) eutectic α+β (Al+Si)

In summary, the studies demonstrate that the use of thermal imaging camera allows for the measurement and recording of cooling and solidification process of silumin. Thermal curves and calculated on the basis the derivative curve have a very similar shape to the curves of TDA obtained from the thermocouple measurements. Results of studies by TDA thermographic method allow quantitative analysis of the cooling process kinetics of silumin.

4. Conclusions

The study shows that in eutectic silumin:

- TDA thermographic method provides a quantitative analysis of kinetics of cooling and solidification process,
- casting conditions: at a rate of cooling of the liquid alloy ~3 °C/s and average cooling rate in the solidification temperature range 0.14 °C/s causes crystallization of eutectic mixture and also preeutectic phases α (Al), β (Si),
- tested methods of analysis the solidification process have similar values of temperature and cooling rate at characteristic points of the process.

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