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Research Article

A Dilatometric Study of the Alloys of the Al-Fe System

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Abstract

The paper presents the results of the dilatometric study of alloys based on the Al-Fe system. The alloys were obtained by classic casting technique. The studies were carried out on samples after casting and annealing. Phase transformation and thermal expansion investigations of the alloys from the Al-Fe system with Al concentration of 38 and 48% at. are discussed. The linear thermal expansion α was calculated by standard method. The α coefficient as a temperature function was noticed. The knowledge on the phase transformations in these alloys including the information about order-disorder transition is very important from the point of view of obtained mechanical and physical properties of alloys of the Al-Fe system. The results are a valuable supplement for development of knowledge of these alloys.

Keywords: *Alloys from Al-Fe system, dilatometric analysis, thermal expansion,*

Introduction

Today, dynamic development of industry and industrial technologies, as well as constant increase in performance of machines and equipment, requires studies on modern materials with unique physical and chemical properties. many ideas and ready solutions for industry wait for proper materials which will enable their realisation. Studies on modern materials are dictated by the fact that the potential of construction materials commonly used now, including most of all conventional and creep-resisting steels, are nearly exhausted, and they are not able to satisfy the constantly increasing commercial requirements. Materials with high specific strength and good resistance to influence of corrosive environments meet with particular interest. Alloys based on a matrix of intermetallic phases are the most promising group of materials.

Special interest is focused on alloys of the Al-Fe system which – together with many alloys of Al-Ni and Al-Ti systems – are a subject for studies from the point of view of their application as construction materials for work at elevated temperatures, what is related, among others, with their high melting points. They are also interesting due to their numerous unique characteristics, *i.a.* high resistance to oxidation, carbonisation, and sulfurisation, high resistance to corrosive action of seawater and liquid solutions of salts, including strongly oxidising nitrogen salts and NaCl-Na_2CO_3 , high electrical resistance at room temperature, good abrasion resistance, erosion resistance and cavitation resistance. Lower density and lower price while compared to currently used stainless and acid-proof steels, containing expensive and scarce alloying elements, such as Cr, Ni, and Mo are important factors recommending application of the alloys of the Al-Fe system. In spite of their numerous advantages, the main barrier limiting application of these alloys for construction elements consists in susceptibility to brittle cracking in air at room temperature and still comparatively low plasticity.

Studies carried out in the scope of their plasticisation, focus on correlations between the three main factors influencing performance of both this and any other group of materials, *i.e.* chemical composition, structure, and manufacturing technology. Deep understanding of phase transformations and properties of the individual phases occurring in the alloys of the Al-Fe system, with particular consideration for intermetallic phases constituting the matrix of possible construction materials– FeAl and Fe_3Al – is one of the aspect of the research carried out.

Material and methodology of research

The material for the research consisted of samples taken from binary alloys of the Al-Fe system, containing 38 and 48% at.

Table 1. Chemical composition of the investigated alloys (%at.)

Alloy	Contents of alloying elements, % at.					
	Al	Fe	Mo	Zr	C	B
Fe-38Al	38.00	61.64	0.20	0.05	0.1	0.01
Fe-48Al	48.00	51.64	0.20	0.05	0.1	0.01

Al, prepared using Vacuum Indication Melting (VIM) technique with triple refining remelt, and gravitational casting. Chemical composition of the alloys is shown in Table 1. Then, the studied material was subjected to

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Table 2. Experimental parameters for the studied alloys

Research alloys	Heating rate, °C/min.	Heating temperature range, °C	Working atmosphere	Gas flow rate	Type of the heating element
Fe-38Al	5	20 - 1350	argon	1.25 l/h	Furnace thermocouple of S type (Pt - Pt-Rh 10%)
Fe-48Al		20 - 1280			

homogenising treatment at 1000°C for hold time of 24 h, and furnace cooling. Temperature of the heat treatment was chosen considering the phase fields present in the phase equilibrium diagram. Dilatometric research was carried out using a SETSYS thermal analyser from SETARAM. The experiment was carried out using the following parameters (Table 2).

In order to carry out the study, a TMA header was used for elongation measurement. During the experiment, the sample was placed under inert argon atmosphere (Ar 99.999%). Determination of temperatures of the beginning and the end of the transition was realised using the method according to the PN-68/H-04500 standard. In the case of lack of distinct effect in the dilatometric curve (Displ), also the effects visible in the differential curve (dDispl). Average coefficient of linear thermal expansion α was determined according to the formula (1).

$$\alpha_{T2-T1} = \frac{l_2 - l_1}{(\Delta T) l_0} \quad (1)$$

Dilatometric research was carried out for the studied alloys in their initial state and after homogenising treatment.

Results and discussion

The dilatometric curve for the alloy 38 is shown in Fig. 1. In the state after casting, the coefficient of linear thermal expansion α of the 38Al alloy changes linearly up to temperature of *ca*. 700°C (1). Above 700°C, the α coefficient increases exponentially up to temperature of the heating end (1350°C), with a slight edge at *ca*. 1260°C (2). During cooling, at the temperature of *ca*. 660°C (3), a slight, however characteristics edge in the dilatometric curve arises – a sudden change in α coefficient, caused by a phase transition. Below temperature of 660°C, $\alpha_2(H)$ phase – an ordered solid solution of FeAl with structure of B2 type (4) forms from the α'_2 phase in the result of a rearrangement of atoms.

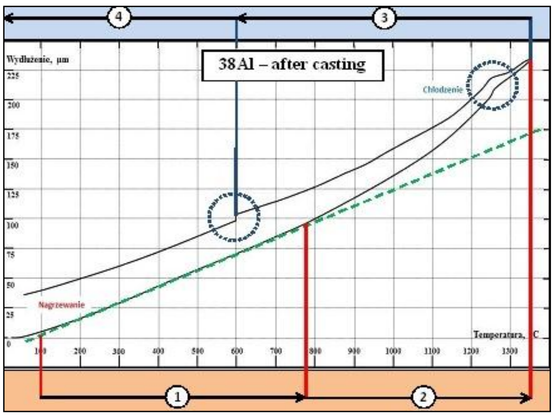

Fig. 1. Dilatometric curve for heating and cooling of 38Al alloy after casting

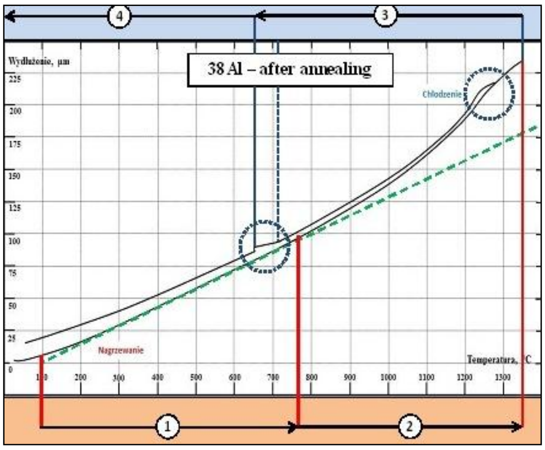

Fig. 2. Dilatometric curve for heating and cooling of 38Al alloy after annealing

After homogenising treatment (annealing), the coefficient of linear thermal expansion α of the 38Al alloy (Fig. 2) changes linearly up to temperature of *ca*. 780°C (1). Above this temperature, it increases exponentially up to temperature of the annealing end (1350°C) (2). During sample cooling, at the temperature of *ca*. 650°C (3), a slight edge in the dilatometric curve arises – a sudden change in α coefficient, caused by $\alpha'_2 \rightarrow \alpha_2(H)$ phase transition (4). Before the edge arises, the slope of the dilatometric curve clearly changes at *ca*. 710°C.

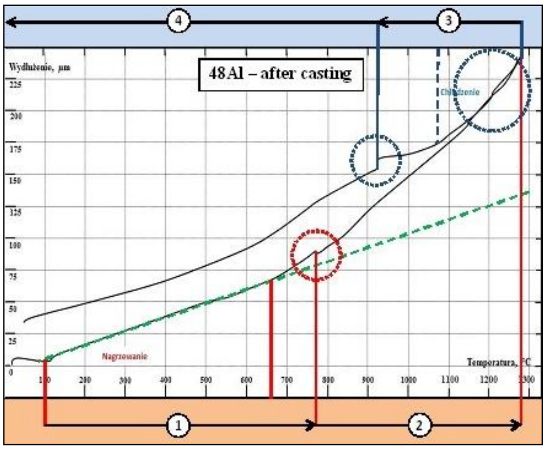

Fig.3. Dilatometric curve for heating and cooling of 48Al alloy after casting

The dilatometric curve for the alloy 48 is shown in Fig. 3. In the state after casting, the coefficient of linear thermal expansion α of the 48Al alloy changes linearly up to temperature of *ca*. 660°C, above which it increases exponentially up to temperature of the heating end (1280°C) (1). At *ca*. 780°C, an edge arises in the dilatometric curve – a sudden change in the α coefficient, probably caused by an $\alpha_2(H) \rightarrow \alpha_2(b)$ phase transition (2). During sample cooling, at *ca*. 1080°C the slope of the dilatometric curve changes significantly, up to temperature of 920°C (3) at which an edge arises – a sudden change in the α coefficient, however an unequivocal identification of this transition is hindered. Below the temperature of 920°C, there are no edges in the plot (4).

After homogenising treatment (annealing), the coefficient of linear thermal expansion α of the 48Al alloy (Fig. 4) changes linearly up to temperature of *ca*. 600°C (1). Above this temperature, it increases exponentially up to temperature of the annealing end (2) No discrete changes in the α coefficient were observed. During cooling, no characteristic edges connected with phase transitions were observed in the dilatometric curve (3).

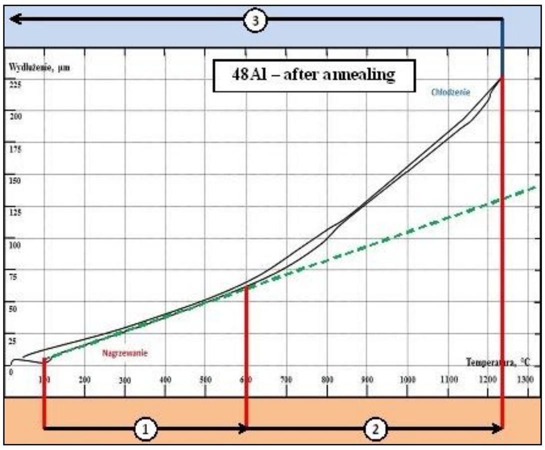

Fig.4. Dilatometric curve for heating and cooling of 48Al alloy after annealing

For the studied alloys, the values of the linear coefficient of thermal expansion α was defined with the assumption of no phase transitions. Nevertheless, considering the fact of the phase transitions occurrence during heating, it was methodologically justified to determine the actual value of α. It is not conventionally used for practical purposes, however, so average α in the range of linear increase in sample dimensions in the investigated temperature range was defined according to the formula (1). The results for 38Al and 48Al alloys are gathered in Figure 5 and Table 3.

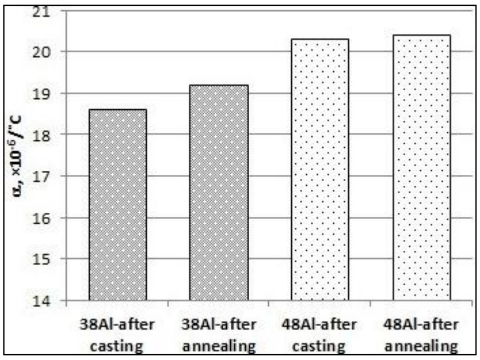

Fig.5. Coefficient of linear thermal expansion for examined materials

Dilatometric studies showed that the increase in aluminium contents is accompanied by an increase in thermal expansion of the studied alloys of the Fe-Al system. In the case of the alloy with 38% at. aluminium contents, in the investigated temperature range of 250°C÷1350°C, average linear coefficient of thermal expansion equals to 18.63×10^{-6} /°C in the state after casting. The heat treatment applied causes an increase in α up to the value of 19.23×10^{-6} /°C. The 48Al alloy is characterised by high thermal expansion; its determined linear coefficient of thermal expansion reaches a value of 20.34×10^{-6} /°C. Homogenising treatment does not influence the α value significantly.

Table 3. List of measured and calculated values from thermal expansion curves for 38Al and 48Al alloys

	$\alpha,\times10^{-6}$ /°C	Δl [%]
alloy 38Al after casting	18.63	2.04
alloy 38Al after annealing	19.23	1.90
alloy 48Al after casting	20.34	2.58
alloy 48Al after annealing	20.42	2.21

Summary

The dilatometric studies carried out allowed for identification of phase transitions occurring during heating and cooling of the alloys, as well as determination of the value of average coefficient of linear thermal expansion for the individual types of the studied alloys in a broad range of the study temperatures. The matrix of the studied 38Al and 48Al alloys is composed of an FeAl phase, and it is in a good accordance with the assumptions and with the phase equilibrium system. The heat treatment used in the form of homogenising annealing influences the homogenisation of the studied alloys, resulting in a convergence of the dilatometric curves during heating and cooling.

The studied alloys of the AlFe system, containing 38 and 48% at. of aluminium, are characterised by a comparatively high thermal expansion defined by the average linear coefficient of thermal expansion. An increase in Al contents in the alloy is accompanied by an increase in the values of average coefficient of linear thermal expansion. However, this dependence is satisfied only up to reaching a stoichiometric composition, *i.e.* up to *ca*. 50% at. of Al contents. Above this contents, a change in the structure occurs: a binary eutectics α_2(b) + $FeAl_2$ forms, and the coefficient of linear thermal expansion decreases.

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