THE COEFFICIENT OF THERMAL EXPANSION OF Fe_3Al AND FeAl – TYPE IRON ALUMINIDES

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Abstract

The iron aluminides seem to be very perspective materials for use in high-temperature structural applications. They are promising materials for a possible replacement of high alloyed steels of P91 or P92 type. But it is very important to know the coefficient of thermal expansion (CTE) of iron aluminides for use as structural materials at high temperatures. It can also be determined phase transformations in the alloy from CTE measurement.

In this paper there were studied the differences in CTE-curves between Fe_3Al ($D0_3$ structure) and FeAl (B2 structure) type iron aluminides. It was investigated the coefficients of thermal expansion and phase structure of three samples in temperature range 440 – 1200 °C.

Keywords: Coefficient of thermal expansion (CTE), Fe_3Al and FeAl – type iron aluminides, HT– dilatation

1. INTRODUCTION

Iron aluminides are alloys of iron and aluminum and they belong into the group of intermetallic materials. These materials are characterized by a wide range of positive properties – for example good strength up to 600 °C, lower density in comparison with the same corrosion-resistant stainless steels, excellent corrosion resistance and also low price of raw materials. All these properties predetermine iron aluminides as structural materials for use in high-temperature applications and aggressive environments. Unfortunately, also some negative properties are by iron aluminides – for example sharp drop in strength above 600 °C or limited ductility at room temperature [1-3]. These disadvantages still make impossible wider use of iron aluminides. Therefore, it is looking ways for improvement of these properties. One possibility is alloying of binary iron aluminides by ternary elements [4-5].

It is needed to take into account beside mechanical properties also the coefficient of thermal expansion (CTE) when material is used for structural applications. The methods for measuring of thermal expansion can be divided into two basic groups – the methods of absolute and relative measurement. The direct measurement of dilatation, X-ray method and interference method are the most frequently used methods from the group of absolute measurement methods. Among the relative methods of dilatation measurement belongs the tube-method, interference or strain-gauge method [6].

The dilatometer-machines can be divided into horizontal and vertical types according to the structural design. Both types of machines have advantages and disadvantages. The horizontal dilatometers have minimal thermal effect on the sample itself. The disadvantage of this arrangement is the friction that occurs between the sample and the holder [6, 7].

The medium coefficient α_{med} is determined from the relationship (1):

$$\alpha_{med} = \frac{l_T - l_0}{T - T_0} \cdot \frac{1}{l_0} \tag{1}$$

l_T – length of the sample at the given temperature; l_0 – length of the sample at the room temperature (20°C)

T – given applied temperature; T_0 – room temperature (20°C)

Recently expansion tests of iron aluminides were describe in [8, 9].

2. MATERIALS AND EXPERIMENTAL METHODS

All samples of iron aluminide alloys were prepared by vacuum induction melting and casting. The nominal chemical composition of the investigated samples is given in ***Table 1***. For dilatation measuring the prismatic specimens (of approximately 15x7x7 mm) were cut on the precise saw Isomet 1000. Thermal expansion was measured by means of horizontal dilatometer. Applied temperature cycle for dilatation measurement is given in ***Table 2***. Repeatedly reached deviation was from 5 to 7% in the temperature range 25 – 600 °C, 2 – 4% in range 600 – 1000 °C and 0.5 – 1% in range 1000 – 1200 °C. The example of registered expansion curve is shown in ***Fig. 1*** [10]. The microstructure was observed after oxide-polishing by suspension OP-S by the light optical microscope (LOM) Nikon Epiphot 200 (with use Nomarski Differential interference contrast – DIC) and by scanning electron microscope (SEM) Zeiss Ultra Plus. The phase composition was studied by SEM equipped with Oxford 20 mm^2 detector for energy dispersive analysis (EDX) and with EBSD.

Table 1 – The nominal chemical composition of the investigated samples

sample	at. %					
	Fe	Al	Cr	Zr	C	B
Fe30Al3.7Cr0.3Zr0.2C (Alloy 1) [10]	balance	29.7	3.7	0.3	0.2	-
Fe30Al (Alloy 2)	balance	29.9	-	-	-	-
Fe40Al0.1ZrBC (Alloy 3)	balance	40.3	0.03	0.09	0.04	0.04

Table 2 – The applied temperature cycle for dilatation measurement

step	conditions
1	25 – 250 °C → heating rate 7 °C / min
2	250 – 1200 °C → heating rate 4 °C / min
3	1200 °C → stamina at temperature 15 min
4	1200 – 700 °C → cooling rate 4 °C / min
5	700 – 25 °C → cooled at a rate less than 4 °C / min

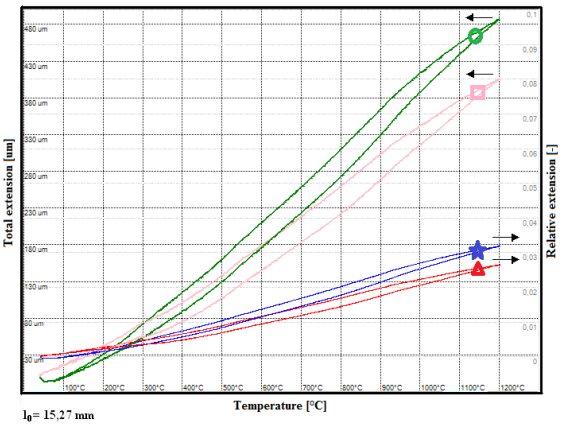

Fig. 1 – Expansion curve of the Fe30Al3.7Cr0.3Zr0.2C [10]

green curve (circle) – The total extension of the system (sample + sapphire adapter rod)
pink curve (square) – The absolute extension of sample
blue curve (star) – The relative extension of the system
red curve (triangle) – The relative extension of the sample

3. RESULTS AND DISCUSSION

3.1 Microstructure and phase identification

The structure of **Alloy 1 (Fe30Al3.7Cr0.3Zr0.2C)** is shown in ***Fig. 2***. The grains of alloy are coarse with dimensions in order of hundreds micrometers. In the structure there are observed particles of Laves phase, sometimes with ZrC core. These particles are distributed on grain boundaries and also inside the grains. Unfortunately their distribution is inhomogeneous, in some places they coalesce into clusters. Chromium was completely dissolved in the matrix. It is consistent with Fe-Al-Cr ternary diagram [11].

Fig. 3 shows the structure of binary **Alloy 2 (Fe30Al)**. The matrix is very coarse-grained with the grains dimensions in order of hundreds micrometers. No particles are presented in the structure in accordance with binary diagram [1].

The grains of **Alloy 3 (Fe40Al0.1ZrBC)** are very similar to the previous alloys. They are coarse and their dimensions are in order of hundreds micrometers. The structure of Alloy 3 is shown in ***Fig. 4***. In the structure there are distributed very homogeneously small needles of secondary phase particles. These particles were identified by EDX and EBSD as perovskite-type Fe_3AlC_x.

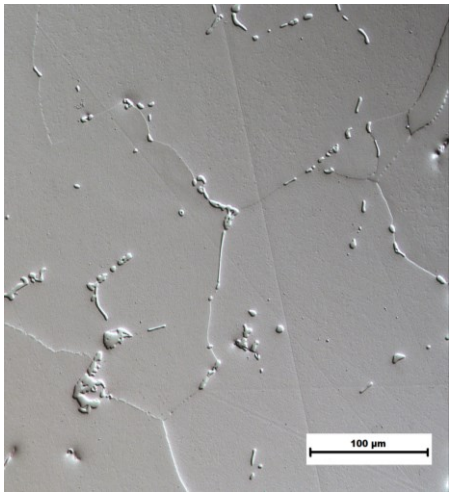

Fig. 2 – The structure of Alloy 1 (Fe30Al3.7Cr0.3Zr0.2C) [10]

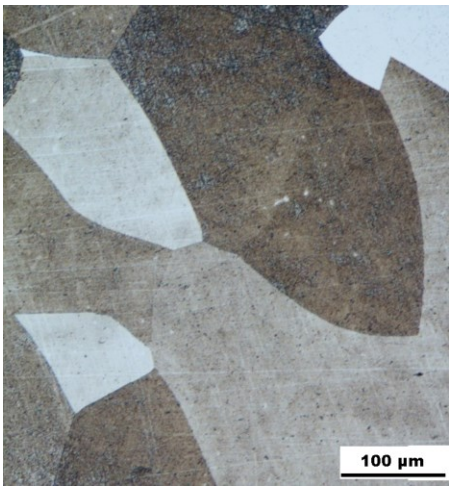

Fig. 3 – The structure of Alloy 2 (Fe30Al)

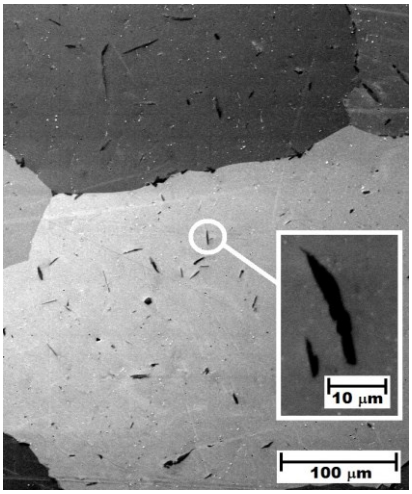

Fig. 4 – The structure of Alloy 3 (Fe40Al0.1ZrBC)

3.2 Coefficient of thermal expansion (CTE)

In the case of Fe_3Al-type alloys (Alloy 1 and 2) is seen the transitions $D0_3 \leftrightarrow B2 \leftrightarrow \alpha(Fe)$ very well from CTE curves. In both cases $D0_3$ matrix exists up to approximately 540 °C. B2 matrix is presented in temperature range 540 – 980 °C and above 980 °C α (Fe) forms the matrix (see ***Fig. 5***). These temperatures of transitions are in agreement with binary diagram in ***Fig. 6***. No temperature shifts of transitions were observed in the case of alloyed sample Fe30Al3.7Cr0.3Zr0.2C. It can be assumed that addition of chromium and small amount of zirconium and carbon has no influence on transformations temperatures.

From CTE curve of FeAl-type alloy (**Alloy 3**) is clearly seen that there have been no transformations (from ***Fig. 6*** is obvious that only one phase transformation for Fe40Al alloy occurs at approximately 1200 °C – $B2 \leftrightarrow \alpha$ (Fe)). From the chart it is also visible that the slopes of CTE curves in B2 areas are parallel for the Fe_3Al and FeAl-type alloy. This means that the expansion rate is the same for the same type of matrix.

The maximum CTE in whole investigated temperature range shows **Alloy 3**. It is due to its chemical composition, because this alloy contents 40 at. % of Al and has B2 structure from room temperature up to

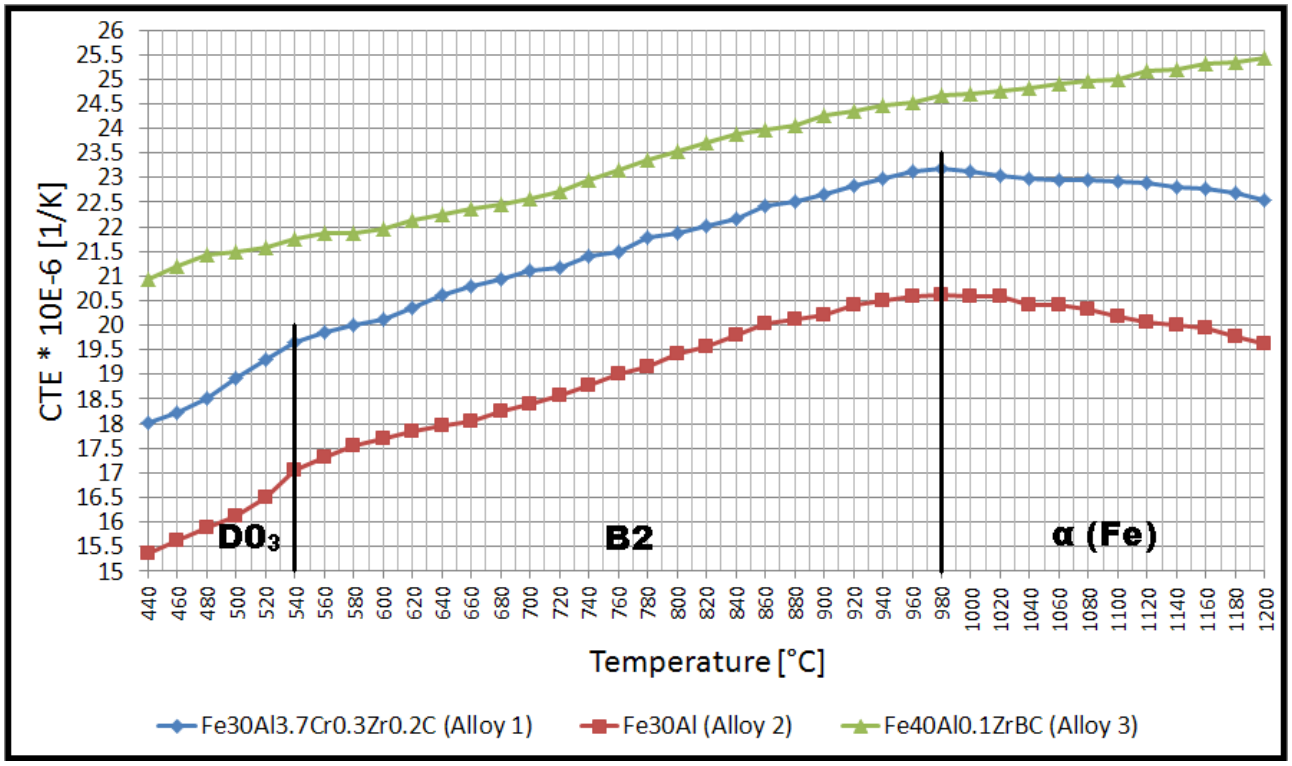

Fig. 5 – The CTE chart of investigated alloys

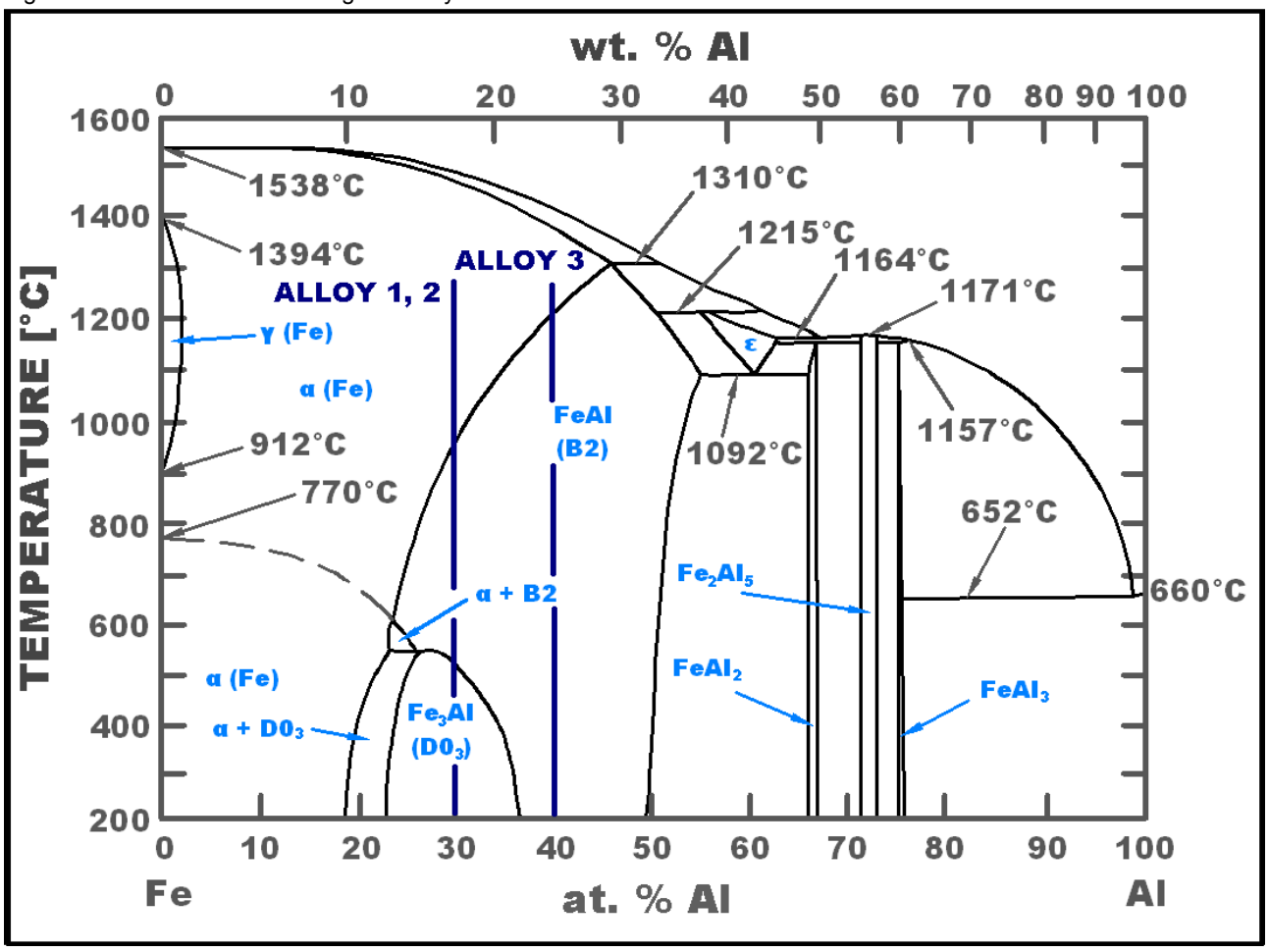

Fig. 6 – The binary Fe – Al diagram with marked composition of investigated alloys

1200 °C. With increasing aluminium content increase CTE values, because thermal expansion for aluminium is twice in comparison to iron. The CTE curves for both Fe_3Al-type alloys are parallel. The values of CTE for **Alloy 1** are about 2.5 1/K higher than in the case of **Alloy 2**. It can be caused by addition of chromium. Chromium is dissolved into the matrix and expands it.

4. CONCLUSIONS

- The Coefficient of thermal expansion of Fe_3Al and FeAl – type iron aluminides was investigated on three samples. Alloy with 40 at. % of aluminium (with B2 matrix) exhibits the highest CTE values from all investigated samples. The CTE increases with increasing aluminium content.
- The addition of chromium into Fe30Al-type iron aluminides causes increasing of thermal expansion
- The slopes of CTE curves in B2 areas are parallel for all alloys. The expansion rate is the same for the same type of matrix.
- From CTE records they were determined transformations temperatures for Fe30Al-type alloys:
    - $D0_3$ matrix up to 540 °C
    - B2 matrix from 540 to 980 °C
    - α (Fe) matrix above 980 °C

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