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The melting diagram of the Ti–Dy–Si system in the Ti–Ti_5Si_3–Dy_5Si_3–Dy region

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The phase equilibria in the Ti–Ti_5Si_3–Dy_5Si_3–Dy part of the Ti–Dy–Si system were studied by DTA, X-ray diffraction, metallography and EPMA. The melting diagram, isopleths at 5Si, 65Ti and 65Dy, and a reaction scheme were constructed. The solidus surface is characterized by the following three-phase fields: ⟨β-Ti⟩ + ⟨Ti_5Si_3⟩ + ⟨TiDySi⟩, ⟨β-Ti⟩ + ⟨TiDySi⟩ + ⟨α-Dy⟩, ⟨TiDySi⟩ + ⟨α-Dy⟩ + ⟨Dy_5Si_3⟩, and ⟨Ti_5Si_3⟩ + ⟨TiDySi⟩ + ⟨Dy_5Si_3⟩. The first two fields form via U-type equilibria, L + ⟨Ti_5Si_3⟩ ⇄ ⟨β-Ti⟩ + ⟨TiDySi⟩ and L + ⟨β-Ti⟩ ⇄ ⟨TiDySi⟩ + ⟨α-Dy⟩, at 1320 and 1170 °C, respectively. The third three-phase field results from an invariant eutectic four-phase equilibrium, L ⇄ ⟨TiDySi⟩ + ⟨α-Dy⟩ + ⟨Dy_5Si_3⟩, at 1157 ± 6 °C. The fourth one is the result of a P-type equilibrium, L + ⟨Ti_5Si_3⟩ + ⟨Dy_5Si_3⟩ ⇄ ⟨TiDySi⟩. The temperature of the latter was estimated to be within the interval 1650–1700 °C.

1. Introduction

In our previous works [1,2], we have shown the positive influence of macroadditions of rare-earth metals R (Dy) on the mechanical properties of titanium alloys with silicon and tin. The elaboration of materials with desirable properties requires a theoretical basis, with information on the phase composition of the alloys, solubility of the components in coexisting phases, the character and temperatures of phase transformations, etc. The phase diagrams group this kind of information. The Ti–Dy–Si system is one of the boundary systems for the Ti–Dy–Si–Sn quaternary [2]. Information concerning the phase equilibria in this system can be found in only one work [3], where the isothermal section of the system at 927 °C (Fig. 1) is reported. Data on the character of crystallization of the alloys is absent. Therefore, the goal of this work was the construction of the melting diagram of the Ti–Dy–Si system in the Ti–Ti_5Si_3–Dy_5Si_3–Dy region. Phase diagrams of the boundary binary systems are given in Fig. 2. For the related Ti–Tb–Si system, the section Ti_5Si_3–Tb_5Si_3 was shown to be quasibinary of eutectic type [10]. The eutectic temperature was found to be 1655 °C. Similar features can be expected for the Ti–Dy–Si system, with a somewhat different eutectic temperature.

2. Experimental

The purity of the starting materials was Ti-99.85%, Dy-99.76%, Si-99.999%. The alloys were melted in an arc-furnace with an inconsumable tungsten electrode on a water-cooled copper hearth in an Ar atmosphere purified by a Ti-melt. To achieve homogeneity, the buttons were turned over and remelted three times.

The alloys were studied by DTA, X-ray diffraction, metallography and EPMA.

DTA was performed in a VDTA-7-type device with a W/W-Re thermocouple in helium. The rate of heating/cooling was ∼30 °C/min. Al_2O_3 and ZrO_2 crucibles were used. The liquidus temperatures were taken from the heating curves as the maximum of the thermal effect. In some cases, the liquidus temperatures were taken on cooling as the beginning of the thermal effect. The accuracy of the temperature measurements was estimated to be ±1%.

X-ray diffraction was performed by the powder method in Debye cameras (d = 57.3 mm) with a URS-2.0 device and from a cross section in a DRON-3.0 diffractometer with Cu Kα radiation. The lattice parameters were calculated by least-squares refinements.

EPMA was carried out using a JEOL Superprobe-733 instrument.

3. Results and discussion

The eutectic character of the Ti_5Si_3–Dy_5Si_3 section was confirmed by studying two alloys with 37.5 at.% Si. The eutectic temperature was found to be 1695 °C. The section is similar to the Ti_5Si_3–Tb_5Si_3 one. The difference concerns the eutectic temperature. The melting diagram of the Ti–Ti_5Si_3–Dy_5Si_3–Dy region of the Ti–Dy–Si system resulting from this investigation is shown in Fig. 3. The phase compositions of the studied alloys are given in Table 1.

The liquidus surface in the investigated area is shown in Fig. 3a. It is formed by the fields of primary crystallization of β, Z, T, ⟨Dy_5Si_3⟩, ⟨β-Dy⟩, and ⟨α-Dy⟩. These are separated by the corresponding curves of joint crystallization.

The location of the monovariant curves and invariant points was established based on examination of the microstructure (Fig. 4). The alloys (80-70)Ti–(10-20)Dy–10Si, (90-65)Ti–(5-30)Dy–5Si, (30-15)Ti–(65-80)Dy–5Si (Fig. 4a–c) are located in the field of primary crystallization of the β-phase; the 65Ti–10Dy–25Si alloy (Fig. 4d)

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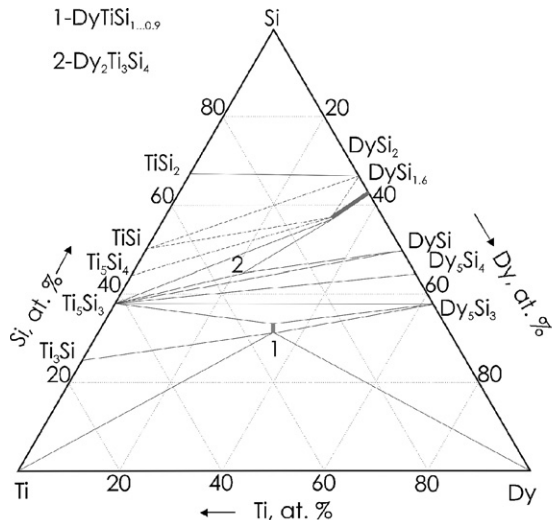

Fig. 1. Isothermal section of the Ti–Dy–Si system at 927 °C [3].

in the field of primary crystallization of the Z-phase; the (65-20)Ti–(20-65)Dy–15Si, 10Ti–80Dy–10Si and 37.5Ti–37.5Dy–25Si alloys (Fig. 4e and f), the 20Ti–50Dy–30Si, 10Ti–65Dy–25Si and 5Ti–80Dy–15Si (Fig. 4g and h), and the (5-10)Ti–85Dy–(10-5)Si in the fields of primary crystallization of the phases T, $\langle Dy_5Si_3 \rangle$, and $\langle \alpha\text{-Dy} \rangle$, respectively. The compositions of the 47.5Ti–47.5Dy–5Si and 30Ti–65Dy–5Si alloys (Fig. 4c) and of the 65Ti–20Dy–15Si and 37.5Ti–37.5Dy–25Si alloys (Fig. 4e) are located approximately on the monovariant curves $L \rightleftarrows \beta + T$ and $L + Z \rightleftarrows T$, respectively.

The solidus surface (Fig. 3b), the temperatures of which were determined from DTA data (Table 2), is characterized by the presence of the three-phase fields: $\beta + Z + T$, $\beta + T + \langle \alpha\text{-Dy} \rangle$, $T + \langle \alpha\text{-Dy} \rangle + \langle Dy_5Si_3 \rangle$, and $Z + T + \langle Dy_5Si_3 \rangle$. These result from the invariant processes $L + Z \rightleftarrows \beta + T$, $L + \beta \rightleftarrows T + \langle \alpha\text{-Dy} \rangle$, $L \rightleftarrows T + \langle \alpha\text{-Dy} \rangle + \langle Dy_5Si_3 \rangle$, and $L + Z + \langle Dy_5Si_3 \rangle \rightleftarrows T$, respectively, as shown in the melting diagram in Fig. 3c. The coordinates of the invariant points are summarized in Table 3. The temperature of the last point was estimated as being higher than the liquidus temperature in the alloy 20Ti–50Dy–30Si (1640 °C) and lower than the temperature of quasibinary $L \rightleftarrows Z + \langle Dy_5Si_3 \rangle$ eutectic (1695 °C).

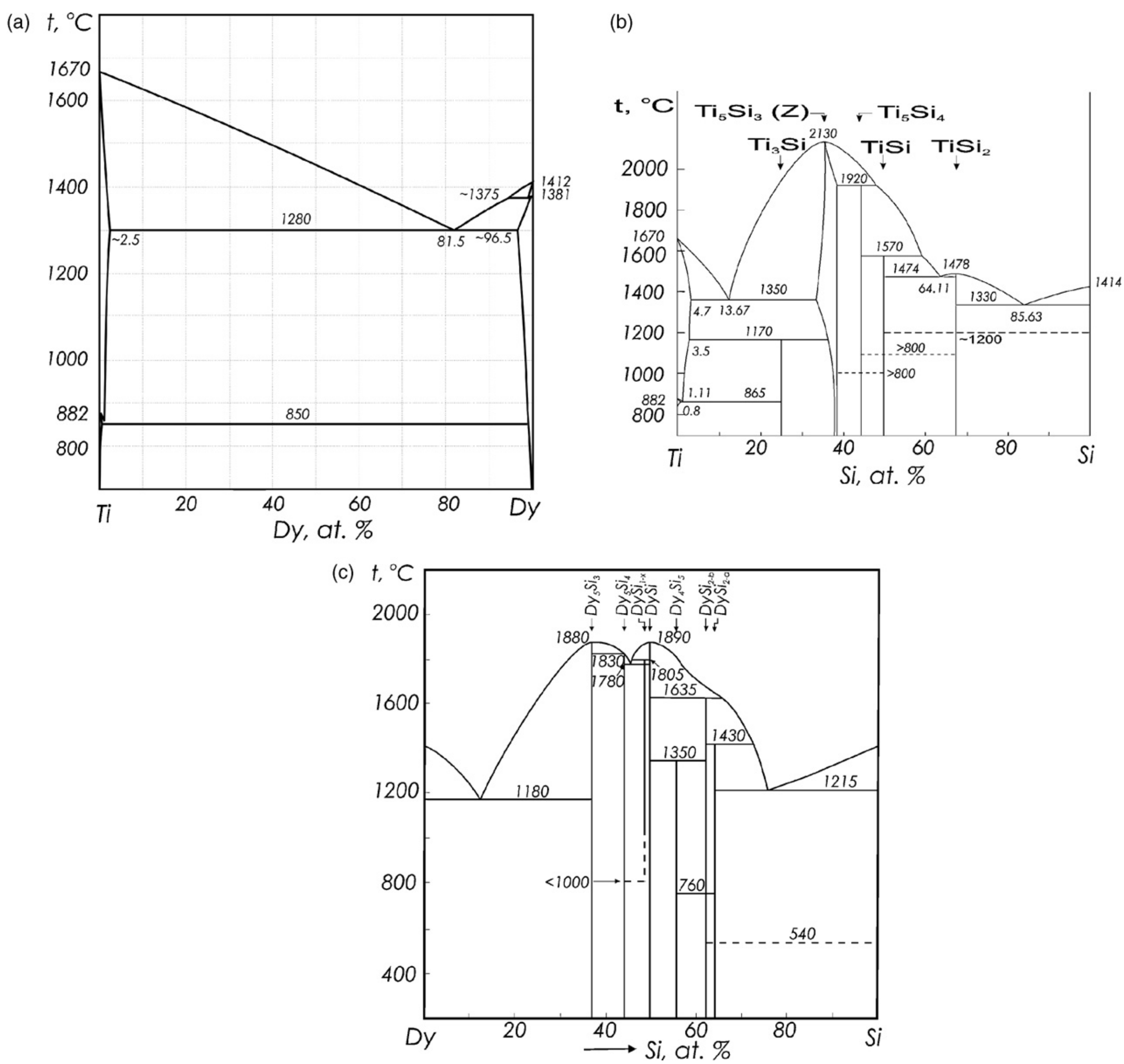

Fig. 2. The boundary binary systems: (a) Ti–Dy [4], (b) Ti–Si thermodynamic optimization [5] of experimental data [6], refinements [7,8], and (c) Dy–Si [9].