

KINETICS OF THE HYDROGEN-INDUCED PHASE TRANSFORMATIONS IN $\text{Sm}_2\text{Fe}_{17}$ ALLOY

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Introduction

Nowadays intermetallic alloy $\text{Sm}_2\text{Fe}_{17}$ deserves attention not just because of its hydrogen absorption and storage ability, but also due to the fact, that hydrogen treatment of this type alloys results in a significant improvement of intrinsic magnetic properties of the intermetallic compound. For example, hydrogen absorption in $\text{Sm}_2\text{Fe}_{17}$ hard magnetic alloy increases the Curie temperature by about 140 K [1].

Rare-earth magnets produced on the basis of Sm and Fe are high-coercivity ferromagnetic materials with high thermal stability and corrosion resistance.

The recently developed HDDR-process is based on hydrogen-induced direct and reverse phase transformations in hard magnetic alloys of the $\text{Nd}_2\text{Fe}_{14}\text{B}$ and $\text{Sm}_2\text{Fe}_{17}$ -type. This hydrogen treatment can be used to obtain the fine-grained microstructure and to increase the coercive force of this type alloys [2,3].

A characteristic feature of these alloys is that upon hydrogenation they lose their thermodynamical stability and at higher temperatures undergo a phase transformation, namely, decomposition into a hydride of a rare-earth component and an α -phase of Fe (in case of $\text{Nd}_2\text{Fe}_{14}\text{B}$ an iron boride Fe_2B is present).

Hydrogen evacuation causes the reverse phase transformation with the formation of the initial fine-grained structure.

At temperatures above 500°C the $\text{Sm}_2\text{Fe}_{17}$ alloy undergoes the direct hydrogen-induced phase transformation (HIPT) described by the following scheme:



This HIPT results in the formation of particles of SmH_2 up to 50 nm in diameter distributed in α -Fe matrix [3].

Reverse phase transformation takes place during hydrogen evacuation at higher temperatures and it can be described by the following reaction:



After the completion of recombination stage the alloy consist of the fine-grained main ferromagnetic phase $\text{Sm}_2\text{Fe}_{17}$ in high-coercive state.

Obviously, the clear outstanding of kinetic peculiarities of the hydrogen-induced phase transformations will allow to control microstructure and magnetic properties of this material.

The purpose of present work was to investigate the kinetics of the hydrogen-induced direct and reverse transformations in $\text{Sm}_2\text{Fe}_{17}$ alloy at temperatures range of 550-750°C and pressure 0.1 MPa.

Results and discussion

The kinetics of direct and reverse HIP transformations was studied using vacuum-hydrogen equipment by Sadikov's magnetometrical method [4].

The experiments were carried out with powder samples (particles were 50-600 μm in diameter).

Fig. 1 shows the isothermal kinetic curves of the direct hydrogen-induced phase transformation at temperatures from 550°C up to 750°C. As can be seen from Fig.1, at 550°C and 570°C (curves 6 and 5) the direct transformation is incompleted and it reaches at 550°C and 570°C 78% and 80% of completeness accordingly. An increasing of temperature of exposure up to 730°C and 750°C (curves 2 and 1) accelerates the phase transformation and it is completed in 160 and 120 min accordingly. Thus, the temperature rising from 550°C up to 750°C causes significant increase of the transformation rate.

It should be emphasized that at all temperatures there is a distinct incubation period, which decreases with the temperature rising.

The results of the kinetic study of the reverse phase transformation are generalized in Fig.2. It should be noted, that at low temperatures hydrogen-induced reverse phase transformation, as compared with the direct one, is characterized by significantly slower transformation rates and larger incubation periods.

At temperatures 550°C and 570°C the reverse phase transformation reaches only 10% and 12% of completeness. At higher temperatures transformation rate significantly rises, and at 730°C the phase transformation is completed in 90 min, and at 750°C it is completed in 25 min.

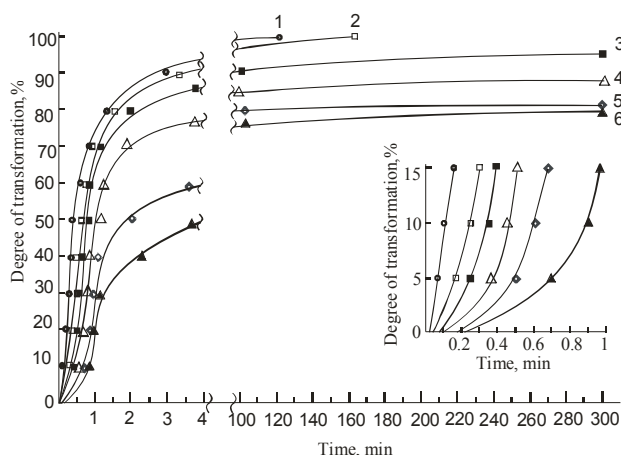


Fig.1 – Degree of the direct phase transformation as a function of isothermal exposure time in hydrogen at temperatures: 1-750°C, 2- 730°C, 3 - 650°C, 4 - 610°C, 5- 570°C, 6 - 550°C.

As it is seen from (1) and (2), the phase transformations of this type require a diffusion transfer of atoms of the alloy components. Two types of diffusional phase transformations are known, namely: spinodal decomposition and transformations that occur by mechanism of nucleation and growth.

Phase transformations that occur by the spinodal decomposition mechanism require very small-distance diffusional displacements of the alloy components and may proceed at rather low temperatures and relatively high rates. The phase transformations proceeding by the nucleation-and-growth mechanism require large-distance diffusion of atoms of the components and, therefore, occur at relatively high temperatures and need much time to be completed.

As can be seen from Fig. 1 and Fig. 2, the direct and reverse phase transformations are characterized by the incubation period, which depend on temperature, and a gradual decrease in the phase transformation rate is detected. These facts indicate that these phase transformations proceed by the nucleation-and-growth mechanism.

For further analysis of the phase transformation mechanism we used the phenomenological theory of Avrami [5], according to which the degree of phase transformation ξ is expressed as:

$$\xi = 1 - \exp(-kt^n),$$

where t is the time, k and n are constants.

Plots of experimental results of the $\ln(-\ln(1-\xi))$ v.s. $\ln t$ axes show the linear behavior. The slopes of the lines give values $n=0.8 \div 2.0$ for the direct transformation and $n=0.8 \div 1.3$ for the reverse transformation.

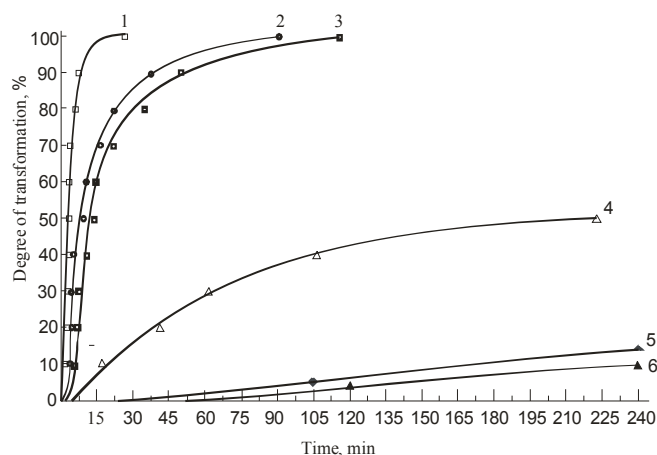


Fig.2 – Degree of the reverse phase transformation as a function of isothermal exposure time in hydrogen at temperatures: 1-750°C, 2- 730°C, 3 - 650°C, 4 - 610°C, 5- 570°C, 6 - 550°C

According to the Avrami theory [5] studied direct and reverse hydrogen-induced phase transformations can be classified as the phase transformations that occur via the nucleation-and-growth mechanism with a diffusion-controlled growth rate of nuclei of new phase.

Hence, it confirms supposition mentioned above, that direct and reverse phase transformations can be identified as hydrogen-induced diffusional ones.

Conclusions

The kinetics of the hydrogen-induced direct and reverse phase transformations in the $\text{Sm}_2\text{Fe}_{17}$ alloy was studied. It was found, that the increase of temperature of the phase transformation from 550°C to 750°C causes a dramatic acceleration of both the direct and reverse phase transformations.

Studied phase transformations are identified as diffusive-controlled ones that proceed by the nucleation-and-growth mechanism.

References

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