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RESEARCH OF THE EFFECT OF Sm_2Fe_{17} ALLOYING WITH TITANIUM AND MOLYBDENUM ON MAGNETIC PROPERTIES

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ABSTRACT

Development of high $Nd_2Fe_{14}B$ based energy-intensive magnets has shown that in principle R-Fe intermetallic compounds with high content of iron are good and relatively cheap magnetic materials. However, a disadvantage of such compounds is the low Curie temperature, which decreases in the R-Fe system with increasing of iron concentration, and becomes the smallest ~ 300-400 K in the case of R_2Fe_{17}. Magnetic properties of the compound can be significantly modified by doping of various interstitial or substitutional impurities. The work presents the results of the investigation on the effect of Sm_2Fe_{17} alloying with titanium and molybdenum, in particular, on the Curie temperature (T_C) and magnetic properties. It is shown that Sm_2Fe_{17} alloying with titanium and molybdenum increases the lattice parameter and the volume of the lattice cell without changing the lattice symmetry. When measuring the hysteretic properties of Sm_2Fe_{17} based alloys, it was revealed that the introduction of titanium, as well as molybdenum, leads to a broadening of the hysteresis loop.

Keywords: Sm_2Fe_{17}, energy-intensive magnets, magnetic materials, magnetic properties, hysteretic properties.

1. INTRODUCTION

In recent years, the interest in the research of magnetism of R_2Fe_{17} and $R(Fe,T)_{12}$ type compounds (where T = Ti, V, Mo, W, Cr, Si) with high iron content has increased dramatically due to obtaining on their basis of new compounds with small atoms of light interstitial elements, such as nitrogen and carbon with magnetic ordering temperatures and the effective magnetic anisotropy fields, exceeding the proper values for $Nd_2Fe_{14}B$ compounds [1-11]. Creation of high $Nd_2Fe_{14}B$ based energy-intensive magnets has shown that, in principle, R-Fe intermetallic compounds with high content of iron are good and relatively cheap magnetic materials [12, 13]. However, a disadvantage of such compounds is low Curie temperature, which in the R-Fe system decreases with increasing of iron concentration and becomes the smallest ~ 300-400 K in the case of R_2Fe_{17} containing the largest amount of iron [5, 6, 14]. Magnetic properties of the compound can be significantly modified by the introduction of various interstitial or substitutional impurities [14-19]. These substitutions may lead to an improvement of the magnetic properties of Sm_2Fe_{17} compounds in the context of their application as a hard-magnetic material. Despite the fairly large number of works dealing with the study of magnetic properties of the compounds with light interstitial atoms, these compounds still remain insufficiently studied (in particular, due to the complexity of obtaining single-crystal samples), though being extremely challenging objects for physics and technology of magnetic phenomena.

In this regard, it is of interest to investigate the effect of Sm_2Fe_{17} alloying particularly with titanium and molybdenum on the Curie temperature (T_C) and magnetic properties.

2. MATERIALS AND METHODS

To obtain the Sm_2Fe_{17} system alloy, powders of iron (d_{90} < 300 μm) and samarium (d_{90} < 700 μm) (Figure-1) as well as molybdenum and titanium with a purity of 99.9% were used as the initial components. Investigations were carried out on alloys of the following compositions: Sm_2Fe_{17}, $Sm_2Fe_{16.5}Ti_{0.5}$, $Sm_2Fe_{16}Ti$, $Sm_2Fe_{16.5}Mo_{0.5}$, $Sm_2Fe_{16.5}Ti_{0.25}Mo_{0.25}$, and $Sm_2Fe_{16}Ti_{0.5}Mo_{0.5}$. Mechanical alloying was performed using Pulverisette-4 planetary mill with different rotation speeds according to the technique described in [20]. The duration of the mechanical alloying process was 20 and 40 hours. To prevent oxidation of the initial powder materials, preparation of powders for mechanical alloying and loading into mill bowls was carried out in a sealed glove box in a nitrogen atmosphere. The obtained powders were annealed in vacuum at a temperature of 700ºC for 30 minutes.

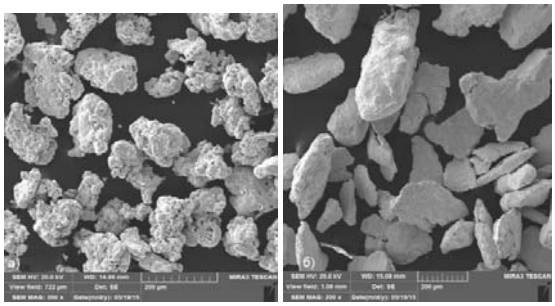

Figure-1. The morphology of initial powders: a) iron, b) samarium.

Phase composition was studied by X-ray diffraction using Brucker D8 Advance diffractometer with

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CuK_α radiation (λ=1,5418Å). The investigation of the structure and distribution of elements in the volume of powder particle was performed using scanning electron microscope Mira 3 Tescan with the Oxford INCA Wave 500 add-on device. Curie temperature (T_C) was determined by the technique described in [21]. Studies of magnetic properties were performed on a vibrating magnetometer at the external field induction of 2.2 T.

3. RESULTS AND DISCUSSIONS

When conducting research on the effect of the mechanical alloying duration on the process of alloying elements dissolution, it was revealed that after 20 hours of mechanical alloying particles of the resulting powder constituted of a layered composite with a non-uniform distribution of alloying elements over the volume (Figure-2). alloying elements dissolution, it was revealed that after 20 hours of mechanical alloying particles of the resulting powder constituted of a layered composite with a non-uniform distribution of alloying elements over the volume (Figure-2). With increasing time of mechanical alloying the distribution of alloying elements over the volume straightens out and after 40 hours of synthesis all the alloying elements are uniformly distributed in the volume of powder and match the chemical makeup of the initial composition (Figure-3).

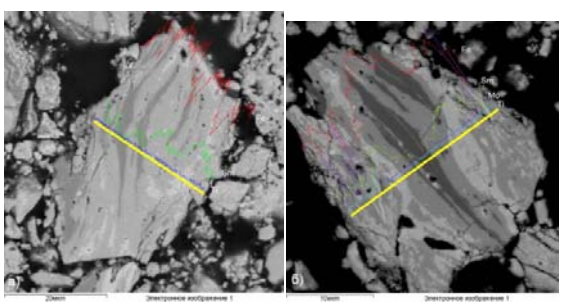

Figure-2. The distribution of elements in the volume of the powder particles obtained by mechanical alloying for 20 hours: a) $Sm_2Fe_{16}Ti_{0.5}$, b) $Sm_2Fe_{16.5}Ti_{0.5}Mo_{0.5}$.

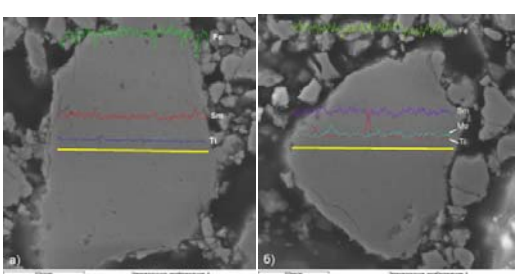

Figure-3. The distribution of elements in the volume of the powder particles obtained by mechanical alloying for 40 hours: a) $Sm_2Fe_{16}Ti_{0.5}$, b) $Sm_2Fe_{16.5}Ti_{0.5}Mo_{0.5}$.

The results of X-ray phase analysis of the studied powders have shown that the main phase component in the samples is the phase with the crystal lattice corresponding to Th_2Zn_{17} type with a small content of α-Fe, samarium oxide, and $SmFe_3$. The addition of alloying elements results in a broadening and simultaneous shift of the peaks, belonging to Th_2Zn_{17}-type crystalline lattice (Figures 4 and 5) that is associated with the change in the crystalline lattice parameter when introducing alloying elements into the Th_2Zn_{17}-type lattice. The measurement results of lattice parameter are shown in Table-1. Presence of α-Fe and $SmFe_3$ suggests that the chemical reaction of Sm_2Fe_{17} formation was incomplete. The formation of samarium oxide, most likely, is caused by oxidation of samarium in the course of preparation of the initial powder composition or in the course of mechanical alloying due to the use of insufficiently pure gas.

During the investigation of the Curie temperature it was revealed that the additional alloying of the initial Sm_2Fe_{17} sample with titanium and molybdenum leads to the increase of the Curie temperature from 139°C (initial alloy) to 165–175°C (Table-2). Determination of magnetic characteristics was performed based on the parameters of the hysteresis loop. Table-2 shows the magnetic characteristics of the studied samples. According to the results obtained, the samples contain the fraction with anisotropy field exceeding 2.2 T; thus the loops turned out to be asymmetric (Figure-6). For the same reason, the values of the fore and reversal magnetization intensity are not the same. Doping of titanium, as well as molybdenum leads to a broadening of the hysteresis loop. The increase in the titanium content results in a slight increase in coercitive force at slight decrease in the residual magnetic induction (Table-2). Simultaneous doping of titanium and molybdenum has a greater impact on the increase of magnetic characteristics.

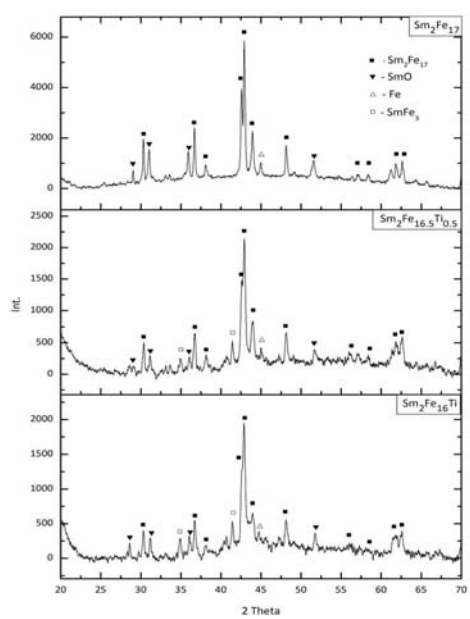

Figure-4. Changes in the phase composition of Sm_2Fe_{17} depending on the content of titanium.

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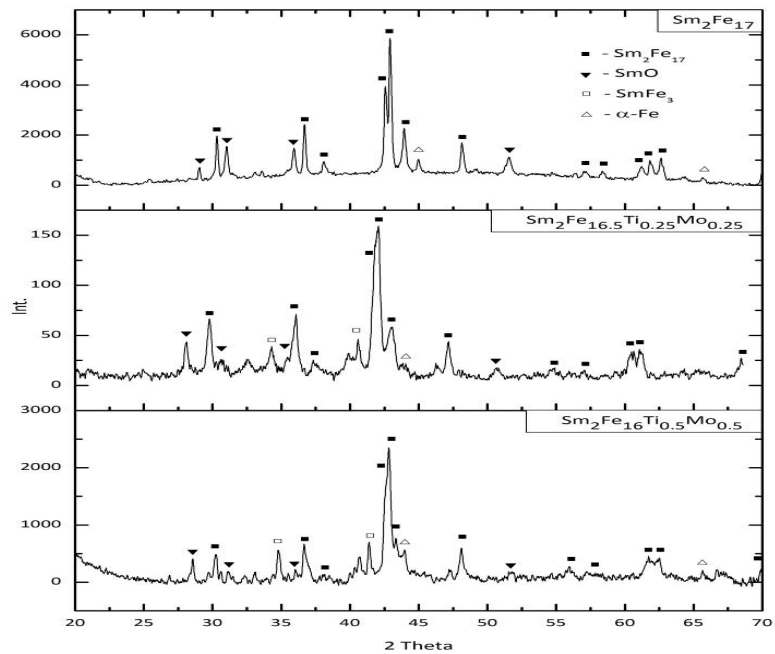

Figure-5. Changes in the phase composition of Sm_2Fe_{17} depending on the content of titanium and molybdenum.

Table-1. Changes in the Sm_2Fe_{17} lattice parameter depending on alloying.

Composition	Lattice parameter		
	a, Å	b, Å	c, Å
Sm_2Fe_{17}	8,551	8,551	12,437
$Sm_2Fe_{16.5}Ti_{0.5}$	8,49371	8,49371	12,33321
$Sm_2Fe_{16}Ti$	8,49371	8,49371	12,33321
$Sm_2Fe_{16.5}Mo_{0.5}$	8,48687	8,48687	12,38000
$Sm_2Fe_{16.5}Ti_{0.25}Mo_{0.25}$	8,48683	8,48683	12,37468
$Sm_2Fe_{16}Ti_{0.5}Mo_{0.5}$	8,50445	8,50445	12,33359

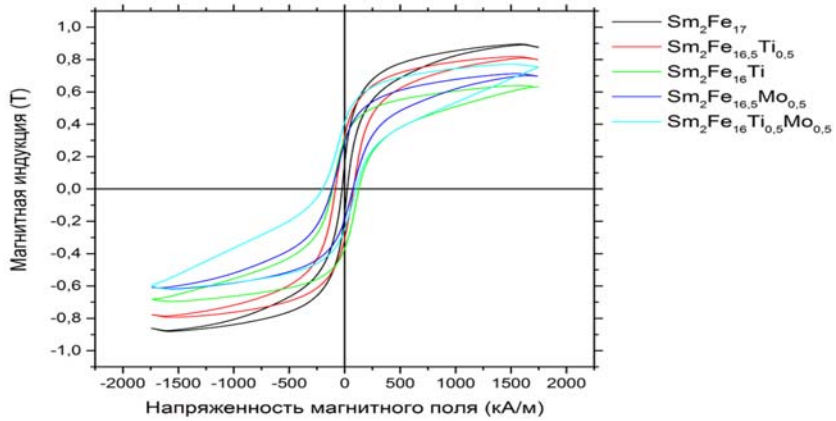

Figure-6. The hysteresis loops for Sm-Fe-Ti, Sm-Fe-Mo, and Sm-Fe-Ti-Mo systems alloys obtained by mechanical alloying.

Table-2. The magnetic characteristics of Sm-Fe-Ti, Sm-Fe-Mo, and Sm-Fe-Ti-Mo systems alloys obtained by mechanical alloying.

N	Alloy	T_C, °C	B_r, T		B_s, T		H_c, kA/m		$(BH)_{max}$, kJ/m^3
			up	down	-2T	2T	left	right	
1	Sm_2Fe_{17}	139	0,165	0,151	0,895	0,880	24,5	22,5	0,99
2	$Sm_2Fe_{16.5}Ti_{0.5}$	166	0,330	0,307	0,817	0,793	89,8	78,4	7,67
3	$Sm_2Fe_{16}Ti$	175	0,310	0,370	0,639	0,695	109,3	123,4	10,00
4	$Sm_2Fe_{16.5}Mo_{0.5}$	165	0,289	0,187	0,618	0,615	115,3	74,1	8,41
5	$Sm_2Fe_{16}Ti_{0.5}Mo_{0.5}$	176	0,402	0,248	0,771	0,616	200,5	99,81	17,89

3. CONCLUSIONS

During research aimed at studying the effect of Sm_2Fe_{17} alloying, particularly, with titanium and molybdenum on the Curie temperature (T_C) and magnetic properties. The alloying of Sm_2Fe_{17} with titanium and molybdenum leads to increase of the lattice parameter and the volume of the unit cell without changing the lattice symmetry. When measuring the hysteretic properties of Sm_2Fe_{17} based alloys obtained by mechanical alloying, it was revealed that the introduction of titanium, as well as molybdenum, leads to a broadening of the hysteresis loop. The simultaneous introduction of both titanium and molybdenum has a greater impact on the increase of magnetic characteristics.

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