Metallurgist, Vol. 50, Nos. 3–4, 2006

DEVELOPMENT AND PRODUCTION OF AMORPHOUS AND NANOCRYSTALLINE MATERIALS

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UDC 539.213:621.318.1

The authors of this article were awarded a Gold Medal at the international exhibition Metal-Expo 2005 for the development and production of amorphous and nanocrystalline materials. The article presents characteristics of mass-produced amorphous and nanocrystalline alloys developed by specialists at the Central Research Institute of Ferrous Metallurgy for use in the electrical and electronics industries.

The creation of new products in electronics and the electrical industry would not be possible without the use of special magnetically soft materials having a unique combination of physical properties (magnetic, electrical, and mechanical). The use of a new class of materials which possess amorphous and amorphous-crystalline (nanocrystalline) structures and exhibit superior static and dynamic magnetic characteristics is making it possible to significantly improve the service properties of a wide range of instruments and components and to develop a new generation of electrophysical equipment. Figure 1 shows the main trends in the use of amorphous and nanocrystalline materials in relation to their physical properties. In recent years, the Central Research Institute of Ferrous Metallurgy (TsNIIchermet) has developed several amorphous and nanocrystalline materials along with methods and equipment for making them.

One important step in the development of commercially viable technologies for making materials of the type being discussed involves the selection of special raw materials. This step includes the development of precision methods of making master alloys and methods for producing special refractories and ceramics. The principles underlying the use of ultrafast quenching to make amorphous alloys were explained in [1]. Various units designed for the ultrafast quenching of melts makes it possible to obtain from 100 g to 50 kg of alloy strip in each casting operation. There is also equipment for casting alloys that contain active components. Designers have now developed a production process that can yield up to 1 ton of strip in each casting operation. Introduction of this process will lead to a 30–40% reduction in the cost of amorphous and nanocrystalline alloys, which will in turn make them competitive with conventional electrical steel for use in serially made transformers.

The volume of production of amorphous and nanocrystalline alloys in Russia is currently tens of tons. Magnetic cores made of these materials are now being made in a wide range of sizes.

Discussed below are the characteristics of mass-produced amorphous and nanocrystalline alloys that have been developed by specialists at tensionIIchermet for use in the electronics and electrical industries.

Class 1. Amorphous electrical alloys and alloys based on the system Fe–Si–B. These materials differ from other amorphous alloys in their high saturation induction. They have unit losses roughly three times lower than the better grades of conventional electrical steel and are recommended for use in the magnetic cores of transformers operating within a wide range of frequencies – including in pulsed magnetization regimes (Table 1). No special operations need to be carried out to apply the layer of insulation.

I. P. Bardin Central Research of Ferrous Metallurgy. Translated from Metallurg, No. 4, pp. 76–78, April, 2006.

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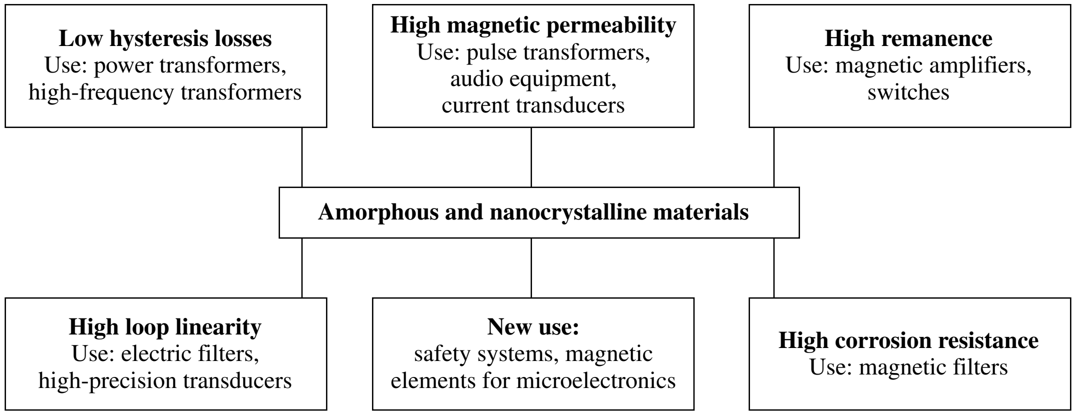

Fig. 1. Main areas of application of amorphous and nanocrystalline materials.

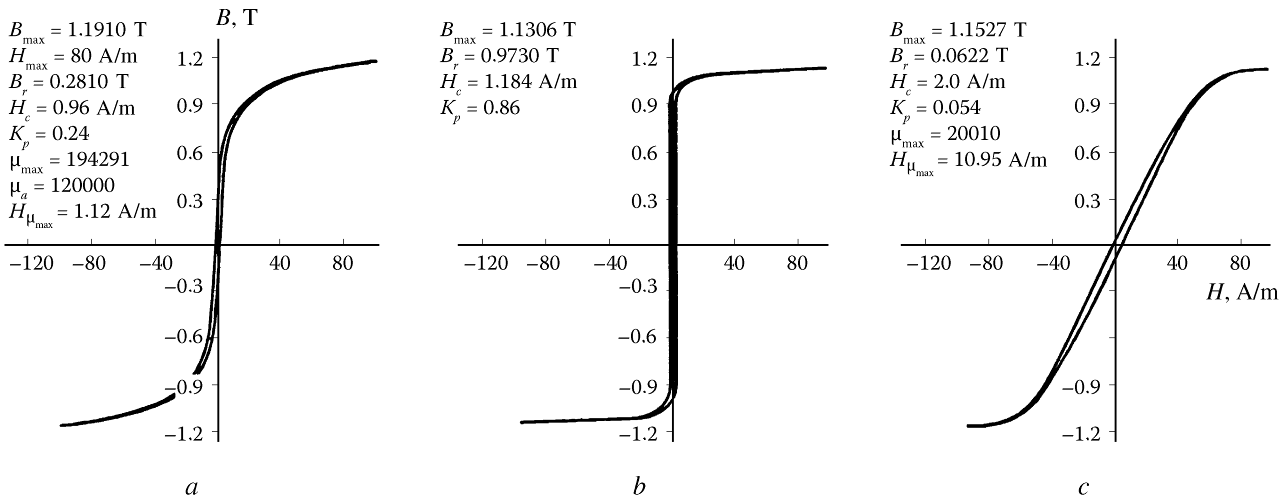

Fig. 2. Hysteresis loops of alloy 5BDSR after heat treatment: *a*) without the application of a magnetic field (S-shaped loop); *b*) in a longitudinal magnetic field (rectangular loop); *c*) in a transverse magnetic field (linear loop).

The alloys and steels shown in Table 1 can be used for the cores of power transformers with a rating up to 500 kVA.

In recent years, researchers have developed amorphous electrical steels based on the system Fe–Si–B–P. The physical properties of these steels and the parameters of transformers with cores made of them are described in [2].

Class 2. Amorphous alloys with maximal magnetic permeability in weak fields have found wide use as magnetic cores for high-frequency transformers, transformers used to measure current and voltage, matching transformers, magnetic modulators, and high-frequency transducers designed to measure magnetic fields.

A wide range of alloys of this type have been developed on the basis of the system Co–Fe–Ni–Si–B, including the following grades: 71KNSR, 84KSR, 84KKhSR, 86KGSR, 82K3KhSR, 82K2KhSR, and 82KGMSR.

The requisite set of properties is obtained in the alloys by heat treatment (HT) or thermomagnetic treatment (TMT). Heat treatment in a longitudinal or transverse magnetic field can form a rectangular or linear hysteresis loop. Table 2 shows typical properties of some of these alloys.

TABLE 1. Characteristics of Amorphous and Electrical Steels and Alloys

Properties	7421	2NSR	9KSR
Magnetic induction B_{2500} at a magnetic field strength of 2500 A/m, T, no less than	1.61	1.40	1.61
Magnetic induction B_{100} at a magnetic field strength of 100 A/m, T, no less than	0.8	0.4	0.5
Unit losses $P_{1.4/50}$, W/kg	0.4	0.5	0.35
Curie temperature, °C	370	420	460
Strip thickness, μm		25–35	
Space factor of magnetic core, %		79–83	

TABLE 2. Characteristics of Amorphous Alloys with Maximal Magnetic Permeability in Weak Fields

Properties	Alloy 84KSR			Alloy 84K3KhSR		
	Type of treatment					
	HT	$TMT_{\parallel}$	$TMT_{\perp}$	HT	$TMT_{\parallel}$	$TMT_{\perp}$
Magnetic induction B_{800}, T	0.70	0.70	0.70	0.58	0.58	0.58
Coercive force H_c, A/m	0.5	0.5	0.7	0.8	0.8	0.5
Initial magnetic permeability μ_a	10^4	$5\cdot10^3$	–	10^5	10^4	10^4
Maximum magnetic permeability μ_{max}	$8\cdot10^4$	$2\cdot10^5$	–	$4.5\cdot10^5$	10^6	–
Orthogonality factor K_p	0.4	0.8	0.05	0.5	0.7	0.05

Note. HT – heat treatment without the application of a magnetic field; $TMT_{\parallel}$ – heat treatment in a longitudinal magnetic field (thermomagnetic treatment); $TMT_{\perp}$ – heat treatment in a transverse magnetic field (thermomagnetic treatment).

Class 3. Nanocrystalline alloys. Alloy 5BDSR is a typical representative of this class of materials. Its optimum level of magnetic properties is obtained in the two-phase state. The structure of the alloy consists of 10–20-nm crystals of α-Fe located in an amorphous matrix [3].

Alloy 5BDSR has a unique combination of high saturation induction, high permeability, and low unit losses during remagnetization. Shown below are the typical properties of alloy 5BDSR after heat treatment without the application of a magnetic field:

Saturation induction B_s, T . . . . ≥1.2
Magnetic permeability:
initial μ_a . . . . $\geq 3\cdot10^4$
maximum μ_{max} . . . . $\geq 10^5$
Coercive force H_c, A/m . . . . ≤1.6
Unit losses P at f = 100 kHz, W/kg 250–280

The heat treatment of magnetic cores of alloy 5BDSR in a magnetic field makes it possible to broadly vary their properties: the coefficient characterizing the orthogonality of the hysteresis loop and the level of magnetic permeability. Figure 2 shows hysteresis loops of different forms that can be obtained by subjecting this alloy to thermomagnetic treatment.

This article has presented some of the properties of amorphous and nanocrystalline alloys that are typical representatives of both classes of materials. The range of materials that have been developed overall is much wider. For special applications, it is now possible to choose materials that have either an optimum combination of properties or have extremely high values of the parameters that are the most important to the service properties of the products in which the materials are used.

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