THE RESISTANCE OF MAGNETIC STATES OF STRUCTURAL STEELS TO EXTERNAL EFFECTS

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The magnetization of a ferromagnet (M) is a function not only of the magnetizing field magnitude (H), but also of a number of factors like temperature (T), variable magnetic field ($H^{\sim}$), mechanical stresses (σ), time, chemical transformations [1]. These factors act only with an external constant magnetic field or when the ferromagnet is in the remanent state. Therefore the remanence observed in structures can result from the action of almost all the above-mentioned factors.

Normal remanence. The mechanisms of the process of ferromagnet magnetization is graphically portrayed by curves showing normal magnetization M as dependent on the magnetizing field H. These curves are referred to as *basic* or *technical magnetization curves*. When the magnetic field is relieved from the technical saturation state, a ferromagnet acquires remanence M_r.

Ideal remanence. Perfect magnetization follows the same laws as normal one and results from nothing more than a variable magnetic field superposed on a constant biasing magnetic field, with the amplitude smoothly varying from the technical saturation state to zero. The remanence obtained on magnetic field relief from the technical saturation field is termed *ideal* M_r^i.

Thermoremanence. A ferromagnet heated to above the Curie point in magnetic field, when cooled in the field, acquires *thermoremanence* M_r^t after the field is relieved.

Piezoremanence and dynamic remanence. The effect of mechanical stresses on a ferromagnet in the presence of magnetic field causes additional magnetization as compared to normal one, whereas without a field it reduces any formerly generated remanence. The remanence occurring under the effect of mechanical stresses in the presence of a field can be of either type after the field is relieved, namely, *piezoremanence* (M_r^p) and *dynamic remanence* (M_r^d).

Chemical remanence. Chemical remanence (M_r^c) is the type of isothermal remanence occurring in the presence of constant magnetic field during changes in the number or volume of ferromagnet phases in chemical reactions.

The maximum remanence values are obtained in different fields. Figure 1 illustrates the regularities of changes in thermoremanence (M_r^t), ideal (M_r^i) and normal (M_r) remanences affected by a magnetic field. The maximum thermoremanence is seen to occur in the weakest fields.

In their turns, variously acquired remanences have different resistances to the action of demagnetizing fields. Figure 2 shows that thermoremanence (M_r^t) is the most resistant to the effect of a variable field. Maximum normal magnetization (M_{rmax}) is less resistant and even less resistant is normal magnetization occurring in weak magnetizing fields.

The resistance of magnetic states to H, σ and T is governed by the magnetic constants of the ferromagnet, the proportion between reversible and irreversible processes and their behaviours during magnetization reversal, i. e., the extent of the interaction of domain walls with different defects, which are numerous in real ferromagnets.

The main reason governing the resistance of magnetic states to the effect of magnetic and electromagnetic fields and elastic strains in steels is domain wall displacement detention due to the interaction of domain walls with magnetic imperfections in a material [2], which mean any defects causing domain wall pinning. A critical field required for the separation of a moving domain wall from a magnetic imperfection depends on the type of the imperfection, therefore the coercive force, which is the averaged characteristic of critical field distribution in a material, depends on various structural factors. A structure-sensitive magnetic characteristic, the coercive force represents the integral properties of a ferromagnet and characterises its general resistance to external effects. More accurate information about the behaviour of the processes of magnetization and magnetization reversal, about the interaction of domain walls with defects of certain types can be gained from studying the resistance of a specific magnetic state, or a number of magnetic states, to the effects of magnetic and electromagnetic fields, elastic and plastic deformations and temperature.

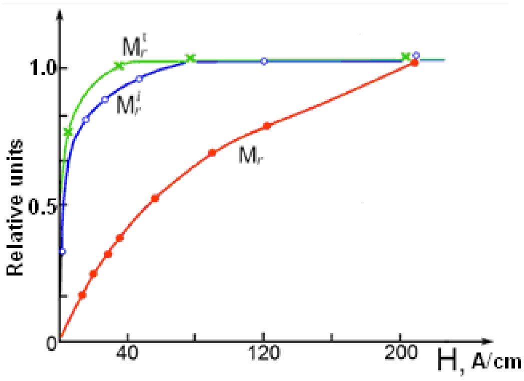

Fig. 1. Field dependences of thermoremanence (M_r^t), ideal remanence (M_r^i) and normal remanence (M_r) .

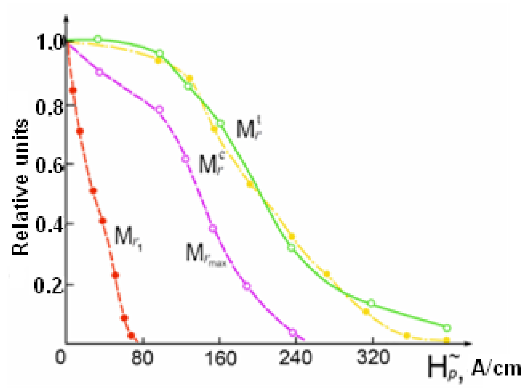

Fig. 2. The loss of resistance of thermoremanence (M_r^t), chemical remanence (M_r^c) and normal remanence (M_r) under the effect of a variable field.

Remanence remanent induction) is a structure-sensitive magnetic characteristic dependent on the structural parameters of a ferromagnet (crystalline structure, grain size, internal stresses, inclusions of various types), magnetic texture, domain texture and its geometric dimensions, i. e., on the distribution of magnetic phases in it. The calculations of remanence made for monocrystalline wires and discs [3] enable its value to be determined fairly accurately. Polycrystalline ferromagnets, where there are numerous additional closure domains located more often on grain boundaries and subdomains appearing near defects, exhibit complex magnetization distribution, therefore calculated data can have a large discrepancy with experimental ones. The occurrence of additional domains and subdomains causes lower experimental values of remanence than those for monocrystalline ferromagnets.

Thus, lower values of remanent induction as compared to theoretical ones bear witness to the presence of magnetic imperfections in a ferromagnet, with a different distribution of magnetization vectors on them.

The remanent state of a ferromagnet is metastable, and its decay under the effect of physical factors like magnetic and electromagnetic fields, elastic and plastic strain and temperature depends on magnetization acquired previously in different ways.

In the remanent state domain boundaries are largely pinned by a variety of magnetic imperfections in ferromagnets resulting from inhomogeneous internal stresses, inclusions, areas of low effective magnetic anisotropy constant. The presence of defects in the structure of steel with corresponding critical fields H_{cr} will govern the extent of interaction of domain walls with them and the resistance of remanence to the effect of constant and variable demagnetizing fields.

The effect of a low-value constant demagnetizing field $H^-{}_{d_1} >> H_{cr_1}$ on a ferromagnet under remanence will displace the domain walls, and they will be pinned in a new position. If the value of the field $H^-{}_{d_1}$ is lowered to zero, the newly acquired state of remanent induction $B^-{}_{d_1}$ will be lower than B_r by $\Delta B^-{}_{d_1}$. The value of $\Delta B^-{}_{d_1}$ will characterize the ferromagnet volume ΔV_1 where the remanent induction has lost its stability under the effect of the demagnetizing field $H^-{}_{d_1}$. The further increase in the demagnetizing field to the value $H^-{}_{d_2}$ will result in a new redistribution of domain walls in the ferromagnet, and the remanent induction will decrease by $\Delta B^-{}_{d_2} = B^-{}_{d_1} - B^-{}_{d_2}$. The value $\Delta B^-{}_{d_2}$ will characterize the volume ΔV_2 of a ferromagnet with critical fields

$H_{cr_1} \div H_{cr_2}$ that has lost the stability of remanent induction under the action of the field $H^-{}_{d_1} \le H^-{}_d \le H^-{}_{d_2}$. The sum of $\Delta B^-{}_{d_1}$ and $\Delta B^-{}_{d_2}$ enables the volume under magnetisation reversal with the critical fields $0 \div H_{cr_2} \le H^-{}_{d_2}$ to be evaluated.

As an example, Fig. 3 shows remanence $B^-{}_d$ as a function of applied demagnetizing field $H^-{}_{d_i}$ for specimens made of steel 34KhN3M tempered at different temperatures. The structural state of the specimens, which was obtained by varying the temperature of tempering, is characterized by different initial values of remanent induction (curve 1 in Fig. 3b). The effect of constant demagnetizing field on constructional steel specimens in the remanent state reduces B_r, however, the resistance of remanent inductions of steels is different for different structural components. Figure 3 represents three regions of resistance of $B^-{}_d$ to constant magnetic field, namely, the region of small demagnetizing fields, when $B^-{}_d$ varies with the field $H^-{}_{p_i}$ only slightly (1), the region of the severest loss of remanent induction stability (2) and the region when a ferromagnet has practically undergone magnetization reversal and is in the remanent induction state close in value to $-B_r$ (3). The field ranges for which regions 1, 2 and 3 are typical are also governed by the structural state of specimens. For example, for a magnetically hard specimen (Fig. 3a, curve 1), region 1 is fairly large ($H^-{}_{p_i}$ varies between 0 and 20 A/cm) and smoothly comes to region 2, which also has a wide range of fields. For magnetically soft specimens tempered at high temperatures (Fig. 3a curve 10), region 1 displays a distinct behaviour corresponding to slight changes in $B^-{}_d$ with the field. Region 2 is characterized by a severe loss of remanent induction stability within a very narrow range of demagnetizing fields.

The high stability of remanent induction in region 1 for specimens tempered at temperatures ranging between 20°C and 250°C and between 500°C and 650°C has to do with the structural state of the steel and, respectively, with the value and distribution of the critical fields. In low-tempered specimens, where the value of critical fields of defects is relatively high, the effect of small demagnetizing fields changes the initial remanence state in small volumes. In high-tempered specimens (up to T_{tem} = 500÷600°C), although the matrix as a whole becomes more perfect (carbon precipitation has practically been completed [5], internal stresses being insignificant), the resistance of the remanent induction of these structures to the effect of weak constant fields increases again (observed on steel 34KhN3M, Fig. 3b, curves 2, 3). This behaviour of remanent induction is due to the increase in the size if carbide particles during coagulation, i. e., the growth of the critical fields of inclusions [2]. The maximum pinning of domain walls occurs on inclusions of “critical” size $d \approx \delta$, where d is the average size of inclusions, δ is domain wall thickness).

On big-size inclusions ($d >> \delta$) closure domains are formed, the magnetostatic energy decreases, and inclusions of the size $d >> \delta$ favour the process of magnetization reversal at fields $H > H_0$. The stability of remanent induction of structures with these inclusions must decrease if applied fields increase the starting field (H_0.) It follows from Fig.3b that the remanent induction of high-tempered specimens (T_{tem} > 600°C), whose structure is a magnetically soft matrix with relatively large inclusions, is the least resistant to the effect of magnetic fields. Thus, the effect of a constant magnetic field $H^-{}_{d_i}$ =10 A/cm (Fig. 3a) leads to a 75% decay of the remanent induction of steel 34KhN3M specimens with T_{tem}>650°C.

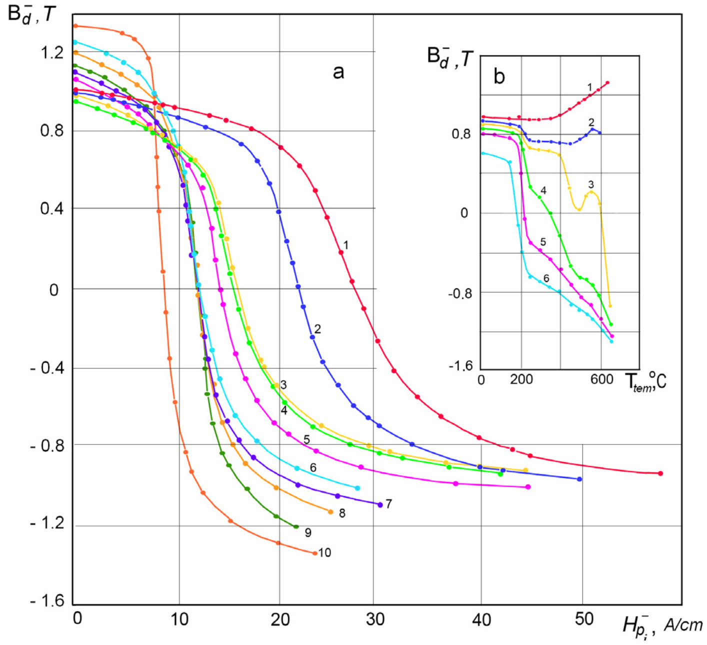

Fig. 3. Induction B^{-}_{d} of toroidal specimens made of steel 34KhN3M as a function of demagnetizing field $H^{-}_{p_i}$ (a) and tempering temperature at $H^{-}_{p_i}$ = const (b). a: 1 – T_{tem} = 20°, 2 – 200°, 3 – 250°, 4 - 300°, 5 – 400°, 6 – 450°, 7 – 500°, 8 – 560°, 9 – 600°, 10 – 650°C; b: 1 – $H^{-}_{p_i}$ = 0, 2 – 10, 3 – 12, 4 – 15, 5 – 18, 6 – 23 A/cm

Conclusion

Thus, the resistance of remanence to external effects depends on the way it has been acquired and the structural state of the steel.

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