Effect of Axial Stress upon Initial Susceptibility of an Assemblage of Fine Grains of Fe_2TiO_4 - Fe_3O_4 Solid Solution Series

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Change in the magnetization of ferromagnetics caused by mechanical stress is of principal interest in the study of magneto-mechanical effects (*Grabovskii and Parkhomenkho*, 1953, *Kapitza and Kalashnikov*, 1952, *Kapitza*, 1959, *Domen*, 1962). The magnetization of natural titanomagnetite under mechanical stresses has been studied experimentally and theoretically by several investigators. However, a systematic experimental study of the problem using a series of synthetic titanomagnetites containing various weight percentages of TiO_2 has not been carried out yet.

A preliminary experimental examination of the problem was carried out using synthetic polycrystallites and assemblages of fine grains of titanomagnetite which represent a typical magnetic mineral in rocks. Eight specimens were prepared for the present study, with $x=0$ to $x=0.7$ in 0.1 steps of $x\text{Fe}_2\text{TiO}_4 \cdot (1-x)\text{Fe}_3\text{O}_4$, on the basis of Taylor's experimental work (1961). The specimens of known chemical composition were synthesized in a controlled oxygen pressure at 1200°C using a mixture of CO_2 and H_2 gases. X-ray diffraction and J_s - T curve measurements were carried out by means of an X-ray diffractometer and an automatic Curie balance, respectively. All specimens were stoichiometric and did not contain any oxidized phases (*Nagata*, 1961, *Syono*, 1965).

The specimen was inserted in a cylindrical nonmagnetic high-pressure vessel with a diameter of 10 mm and compressed from both sides along its cylindrical axis by a hydraulic press. The pressure ranged from zero to 4 kb. It is possible that the purely axial compressional stress within the specimen may be appreciably lowered by the confining pressure of a container, however, it is shown by measurement of the magnetization of a bulk specimen that the distribution of stress in a specimen under axial compression is essentially uniaxial and the smaller the grain size of the specimen, the less will be the difference between uniaxial and confining pressure.

Magnetization of the specimen under repeated compression was measured by a ballistic method (*Nagata and Kinoshita*, 1965). The intrinsic initial susceptibility $\chi_{(o)}^{in}$ was calculated from the magnetization versus external magnetic field curves taking into account the demagnetizing factor N (≈ 0.3 in the present study). An example of relative change in $\chi_{(o)}^{in}$ is shown in Figs. 1-a and b, where four curves represent the change in $\chi_{(o)}^{in}$ with two cycles of repeated compression. Curves in Fig. 1-a were obtained for an assemblage of fine grains of a $0.7\text{Fe}_2\text{TiO}_4 \cdot 0.3\text{Fe}_3\text{O}_4$ solid solution with diameters from 60 to 500 microns, and curves in Fig. 1-b are those of the same specimen with diameters less than 60 microns. We cannot find any difference in the change in $\chi_{(o)}^{in}$ between fine and coarse grains under compression,

Fig. 1 Change in the initial susceptibility of an assemblage of fine grains of synthetic $0.7\text{Fe}_2\text{TiO}_4$ - $0.3\text{Fe}_3\text{O}_4$ solid solution with two cycles of repeated compression (first to fourth curves). Solid curves are for increasing compression. Dotted curves are for release of compression.
 a; for coarse grains with diameters 60 to 500 microns.
 b; for fine grains with diameters 0 to 60 microns.

Fig. 2 Change in the initial susceptibility with compression of 2 and 4 kb as a function of the chemical composition of synthetic magnetite-ulvöspinel solid solutions $x\text{Fe}_2\text{TiO}_4$ -($1-x$) Fe_3O_4 .

By a series of measurements for $x=0.0$ to 0.7 , we found a systematic change in the pressure dependence of $\chi_{(\sigma)}^{\text{in}}$ of a titanomagnetite solid solution series as shown in Fig. 2.

On the stress sensitivity of the initial susceptibility of rocks and rock-forming ferromagnetic minerals, Kern (1961) and Nagata (1966) showed that the change in the initial susceptibility of an assemblage of non-interacting single-domained fine grains under uniaxial compression is expressed by

$$\chi_{(\sigma)} = \frac{\chi_{(0)}^{\text{in}}}{1 + \beta \cdot \sigma}$$

where $\chi_{(0)}^{\text{in}}$ and β denote, respectively, $\chi_{(\sigma)}^{\text{in}}$ at $\sigma=0$ and a positive constant dependent on the magnetic mineral. According to the authors, the coefficient β (stress sensitivity) is theoretically derived as

$$\beta = \frac{3 \cdot \lambda_s}{I_s^2} \cdot \chi_{(0)}^{\text{in}}$$

Therefore, theoretical values of β for the magnetite-ulvöspinel solid solution series can be

Table 1. β calculated from experimental curves in Fig. 2 and from the theoretical expression, using I_s and λ_s for the titanomagnetite solid solution series. λ_s for $0.7\text{Fe}_3\text{TiO}_4\text{--}0.3\text{Fe}_3\text{O}_4$ is an extrapolated value obtained from experimental curves for λ_{111} and λ_{100} (Syono, 1965). $\beta = k \cdot \frac{\lambda_s}{I_s} \cdot 10^9 / \text{kb}$ and $k = 10^{-3}$: i.e., $\chi_{(o)}^{in} = 0.5 \text{ emu/cc}$ for pure magnetite is assumed.

β	x	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Theory	$k = 10^{-3}$	0.13	.31	.62	.90	1.2	1.8	3.9	9.0
Experiment	$\sigma = 0.5 (\text{kb})$	.23	—	.30	—	.55	—	.75	.80
	2.0	.15	.16	.20	.25	.33	.40	.55	.60
	4.0	.13	.15	.18	.21	.28	.35	.40	.45

calculated using the known constants $\lambda_s = \frac{1}{5}(3\lambda_{111} + 2\lambda_{100})$ (isotropic saturation magnetostriction constant) and I_s (saturation magnetization) at room temperature (Syono, 1965). In this case, the absolute value of the initial susceptibility $\chi_{(o)}^{in}$ is roughly approximated by $\chi_{(o)}^{in} \approx k \cdot I_s$, where k is a numerical constant. Though k is strongly dependent on various factors such as grain size or internal residual stress of the specimen, we assume here that the value of k is equal for all specimens now concerned. Experimental and theoretical values of β for the magnetite-ulvöspinel solid solution series are listed in Table 1. A large discrepancy throughout the whole pressure range between theoretical and experimental values implies that a further theoretical consideration of the stress dependence of magnetization for an assemblage of ferromagnetics is needed taking into account the more actual stress distribution in a compressed specimen.

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