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Elastic behaviour of Mn–Zn ferrites

M. K. Moinuddin and S. Ramana Murthy
Department of Physics, Osmania University, Hyderabad 500007 (India)

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Abstract

A series of Mn–Zn ferrites was prepared by a double sintering method. Samples were sintered at various temperatures to obtain different porosities. Ultrasonic velocities were determined by using a pulse transmission method at 10 MHz and the values of the elastic moduli were obtained from the measured sound velocities. The observed experimental results have been explained on the basis of microstructural changes.

1. Introduction

The magnetic properties of Mn–Zn ferrites such as saturation magnetization, permeability, Curie temperature and disaccommodation have been studied in detail [1–3]. Not much emphasis has been given to the mechanical properties of Mn–Zn ferrites, although of late there has been a growing interest in these properties. Information on the mechanical properties of Mn–Zn ferrites is needed in constructing the cores of magnetic videos and audio recording heads [4]. Therefore, we have undertaken a systematic study of preparation and elastic behaviour of Mn–Zn ferrites. The results thus obtained are presented in this paper.

2. Experimental details

The polycrystalline Mn–Zn ferrites having the chemical formula $Mn_{1-x}Zn_xFe_2O_4$ (where x ranges from 0 to 1) were prepared by the double sintering method. Samples were sintered in air at different temperatures to obtain various values of the porosity. In order to study the atmospheric effect, the samples were also sintered in the presence of oxygen. The samples so prepared were characterized by X-ray diffraction and it was found that they were monophasic. The bulk densities of the samples were determined from volume and weight measurements in air, at room temperature with an accuracy of ±0.1%. It was found that the bulk densities were 78%–93% of the X-ray density.

An ultrasonic pulse transmission technique [5] was employed for the measurement of sound velocity in the samples at 10 MHz. The r.f. pulse generated by a pulse oscillator was applied to quartz transducers. The acoustic pulses were converted into electrical signals by the receiving transducers. The output signal was displaced on a digitizing oscilloscope. The difference Δt between two overlapping received pulse trains was noted with the help of a digital timer. The sound velocity V was obtained from $V=L/\Delta t$, where L is the length of the specimen (measured using a digital micrometer). The accuracy of the velocity measurements was ±0.02%. Silicon grease was used as an acoustic coupling adhesive.

Elastic moduli of Mn–Zn ferrites were calculated from measured longitudinal and shear ultrasonic velocities V_l and V_s respectively using the following relations: for the Young's modulus, $Y=V_s^2\rho[3(V_l/V_s)^2-1](V_l/V_s)^{-2}$ and for the shear modulus, $n=V_s^2\rho$ where ρ is the bulk density of the specimen. Values of bulk modulus k and Poisson's ratio σ were also computed using standard formulae.

3. Results and discussion

In Table 1 the preparation conditions such as sintering temperature and sintering atmosphere for Mn–Zn ferrites are presented. This table also gives the values of the X-ray density, bulk density and percentage of porosity.

It can be seen from Table 1 that an increase in the sintering temperature leads to an increase in the values of the bulk density for the samples sintered in air and oxygen atmospheres. This indicates that an increase in the sintering temperature increases the densification in the sample. Table 1 shows that the values of the porosity are in accordance with the values of the bulk density. However, the values of the X-ray density are

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TABLE 1. Density and porosity data for Mn–Zn ferrites at room temperature

	$Mn_{0.8}Zn_{0.2}Fe_2O_4$			$Mn_{0.6}Zn_{0.4}Fe_2O_4$			$Mn_{0.4}Zn_{0.6}Fe_2O_4$			$Mn_{0.2}Zn_{0.8}Fe_2O_4$		
a	b	c	d	b	c	d	b	c	d	b	c	d
Air atmosphere												
1100	5.11	4.00	21.7	5.12	3.92	23.4	5.12	3.98	22.3	5.26	3.81	27.6
1200	5.11	4.12	19.4	5.12	4.01	21.6	5.12	4.06	20.7	5.26	3.86	26.7
1300	5.11	4.23	17.1	5.12	4.10	19.8	5.12	4.15	19.0	5.26	3.90	25.9
1400	5.11	4.35	16.8	5.12	4.18	18.3	5.12	4.20	18.0	5.26	3.95	25.0
Oxygen atmosphere												
1100	5.13	4.82	6.00	5.13	4.80	6.50	5.14	4.60	10.5	5.28	4.25	19.6
1200	5.13	4.85	5.40	5.13	4.84	5.70	5.14	4.75	7.60	5.28	4.40	16.7
1300	5.13	4.90	4.40	5.13	4.87	5.10	5.14	4.90	4.70	5.28	4.50	14.8
1400	5.13	4.95	3.40	5.13	4.93	4.00	5.40	5.05	3.70	5.28	4.63	12.4

a, sintering temperature (°C); b, X-ray density ($\times 10^3$ kg m^{-3}); c, bulk density ($\times 10^3$ kg m^{-3}); d, percentage of porosity.

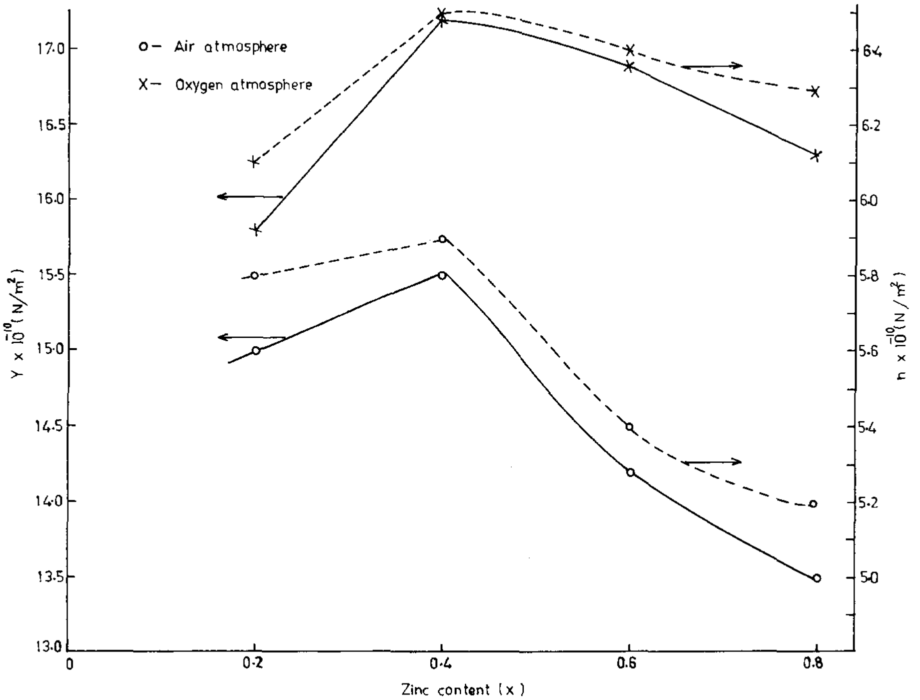

Fig. 1. Variation in Young's modulus Y and rigidity modulus n with zinc content x at 1300 °C.

found to be constant with an increase in the sintering temperature for air and oxygen atmospheres. It is observed that the values of the X-ray density, bulk density and porosity are higher for the samples sintered in an oxygen atmosphere. It can also be noticed from Table 1 that the value of the porosity decreased from 27% to 3% as the sintering temperature was increased from 1100 °C to 1400 °C. Similar changes in bulk density and porosity have been observed by Naik and Powar [6] for Ni–Zn ferrites sintered between 1100 °C and 1250 °C.

The results observed in the present investigation can be understood on the basis of microstructural changes brought about by the sintering conditions. The number of pores is reduced at a higher sintering temperature, as a result of which individual grains come closer to each other and the effective area of grain-to-grain contact increases. This, in turn, results in greater densification or less porosity.

Experimental values of Young's modulus Y and rigidity modulus n together with the calculated value of bulk modulus k are shown in Table 2. It can be observed from the table that the values of Young's and rigidity moduli increase with the sintering temperature up to 1300 °C for the samples sintered in both atmospheres. However, with further increase in sintering temperature to 1400 °C, the values of Y and n are found to decrease. This decrease may be due to the evaporation of zinc

TABLE 2. Elastic data for Mn–Zn ferrites at room temperature

Sintering temperature (°C)	$Mn_{0.8}Zn_{0.2}Fe_2O_4$			$Mn_{0.6}Zn_{0.4}Fe_2O_4$			$Mn_{0.4}Zn_{0.6}Fe_2O_4$			$Mn_{0.2}Zn_{0.8}Fe_2O_4$		
	Y	n	k	Y	n	k	Y	n	k	Y	n	k
Air atmosphere												
1100	14.1	5.40	12.0	15.0	5.70	13.6	13.4	5.10	12.0	12.9	4.90	11.7
1200	14.3	5.50	12.1	15.4	5.80	13.8	13.5	5.20	11.1	13.3	5.10	11.3
1300	15.0	5.80	12.4	15.5	5.90	13.8	14.2	5.40	12.8	13.5	5.20	11.1
1400	14.5	5.60	12.1	15.2	5.80	13.6	13.6	5.20	11.8	13.1	4.80	16.1
Oxygen atmosphere												
1100	15.3	5.80	13.4	16.6	6.30	14.5	16.2	6.20	14.0	15.7	6.00	13.7
1200	15.6	6.00	14.0	16.8	6.40	14.3	16.6	6.40	13.6	16.0	6.10	14.1
1300	15.8	6.10	13.5	17.2	6.50	15.8	16.9	6.40	14.1	16.3	6.30	13.2
1400	15.3	5.80	13.3	16.7	6.40	14.3	16.8	6.40	14.9	15.8	6.10	12.9

Y, n and k are all in units of 10^{10} N m^{-2}.

during sintering at higher temperatures [7]. A similar behaviour was observed in the case of Ni–Zn ferrites [8]. Further, it can be seen from the table that the values of Y and n are high for the samples sintered in an oxygen atmosphere. This may be due to the adequate supply of oxygen to zinc during the sintering process.

The values of Poisson's ratio for the samples sintered in air and oxygen were found to be 0.30 and 0.31 respectively. This shows that the samples under investigation are ductile in nature.

The variation in Young's and rigidity moduli with concentration x of zinc, for samples sintered in air and oxygen atmospheres at 1300 °C, is given in Fig. 1. A similar variation in these moduli with zinc concentration was also observed for all other Mn–Zn ferrites sintered at various temperatures (not shown here). It can be observed from the figure that the values of Y and n increase with addition of zinc content up to 0.4 mol. With further addition of zinc, the values of Y and n are found to decrease up to 0.8 mol. Following Wooster's explanation [9], this observed result can be interpreted in terms of binding energy. An addition of 0.4 mol of zinc ferrite to manganese ferrite increases the binding energy between the atoms. A further increase in zinc content weakens the atomic binding. This observation is in agreement with the results of many other mixed ferrites [10, 11].

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