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Recent Activities in Research of Soft Ferrite

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The body can be viewed from the next page.

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1 Introduction

Soft ferrite has much higher resistivity than metallic soft magnetic materials and provides excellent soft magnetic properties at frequencies between tens of kilohertz and hundreds of megahertz. Therefore, this ferrite is used in the cores of high-frequency transformers, choke coils, noise filters, etc. While growth in demand for soft ferrite is somewhat low in Japan, on a global basis, demand for soft ferrite for consumer-oriented electronic equipment such as personal computers and cellular phones, which are coming into widespread use, is increasing, and customers are requiring further cost reduction, smaller and thinner design, and higher frequency capacity and performance.

Due to this background, Kawasaki Steel branched out into the MnZn soft ferrite business in October 1990 at the Mizushima Works of Kawatetsu Magnex Corp. (now Kawatetsu Ferrite Corp.). Kawasaki Steel developed new materials of MnZn ferrite and the manufacturing process necessary for embarking on this new business in a joint effort with Kawatetsu Ferrite Corp. To date Kawasaki Steel has developed four types of low-loss materials for switching power supplies, five types of high-permeability materials[1] and a precisely atmosphere-controlled roller hearth type kiln[2] that combines high quality and high productivity.

2 Development of Low-Loss MnZn Ferrite for Power Supplies

In the switching power supplies used in various types of electronic equipment, technological innovation is moving toward smaller size and higher performance. In the soft ferrite cores that are the principal component materials for transformers, the development of new techniques is concentrating on the lowering of losses at high frequencies of 100 kHz or more[3].

The core losses of MnZn ferrite are composed of hysteresis losses, eddy current losses and residual losses. When the switching frequency range widens to 100 kHz through 1 MHz, the proportions of these three kinds of losses relative to each frequency differ. In view of this fact, the company developed general-purpose low-loss materials, MB3[4], MB4[5] and MBT1 for frequencies from 100 kHz to 500 kHz and a low-loss material, MC2 for high frequencies from 500 kHz to 1 MHz. The effects of composition and trace additives on the above core loss factors in each frequency range and effects of manufacturing conditions (mainly on grain structure control) were quantitatively analyzed, and lower losses were obtained by optimizing the following five factors:

(1) Average grain size and grain size distribution in the core
(2) Sintered density and pore distribution in the core
(3) Formation of a high-resistivity phase at grain boundaries by trace additives
(4) Homogeneity of composition and components
(5) Residual stress

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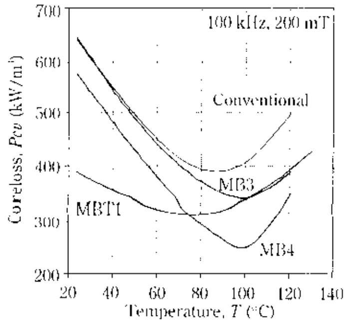

Fig. 1 Temperature dependence of core loss at 100 kHz and 200 mT of low loss materials, MB3, MB4 and MBT1 in comparison with the highest quality core manufactured by a conventional method

Figure 1 shows the temperature dependence of core losses of MB3, MB4 and MBT1 in a standard ring core as compared with the highest grade commercial material before the development of these Kawasaki Steel products. Core losses were improved by about 20% in MB3 compared with the commercial material and a further 20% improvement in core losses was achieved in MB4 compared with MB3. In MBT1, the temperature dependence of core losses in the temperature range from room temperature to about 100°C has been substantially improved. Core losses at 100°C are kept at levels of MB3 and reduced to about 60% of those of MB3. Thus, MBT1 can realize low-loss transformers in a wide temperature range from room temperature to about 100°C and meet public demand for energy savings.

3 Development of High-Permeability MnZn Ferrite

MnZn ferrite can provide the highest initial permeability of all types of soft ferrite and is used in a relatively low frequency range of up to a few tens of megahertz. Kawasaki Steel developed high-permeability materials MA055 to MA150 (relative initial permeability of 5 500 to 15 000) with improved frequency characteristics for use in the cores of noise filters used in this frequency range and those of pulse transformers used in digital communication equipment[1]. The frequency dependence of initial permeability of various types of high-permeability materials is shown in **Fig. 2**.

In order to increase the initial permeability of a ferrite core, it is necessary to select a composition that makes both magnetic anisotropy and magnetostriction zero. At the same time, it is necessary to form magnetic domain walls that move easily by making large and uniform grain sizes and to reduce defects, pores, impurities, etc. that prevent the motion of domain walls as much as possible. It is especially important to select raw materials that contain as few impurities as possible, and consequently, Kawasaki Steel developed the high-quality iron oxide KH-CPW[6] as a raw material for high-performance ferrite synchronically in Chemical Division.

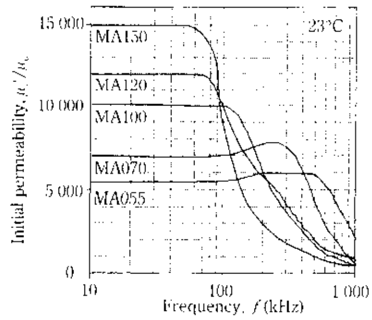

Fig. 2 Frequency dependence of initial permeability at 23°C high permeability materials, MA 055~MA150

It is also necessary to reduce magnetic losses that occur with an increase in frequency in order to keep high permeability at higher frequencies. This is done by improving the frequency dependence of initial permeability. For this purpose, trace additives were made to precipitate at grain boundaries to raise the resistance of the grain boundaries, which in turn improved the frequency dependence by reducing eddy current losses. When only additives are increased and other manufacturing conditions are kept constant, the value of permeability decreases.[7] In view of productivity, therefore, manufacturing conditions are determined by making a compromise between the improvement of the frequency dependence and the degradation of permeability. This problem can be solved by introducing the precisely atmosphere-controlled roller hearth type kiln[2], which will be described in the next section. Short-time simultaneous sintering was achieved under the same sintering conditions as with the low-loss materials described in the preceding section.

4 Development of a Precisely Atmosphere-Controlled Roller Hearth Type kiln

Sintering furnaces for MnZn ferrite are divided into batch-type box furnaces and continuous tunnel furnaces, and pusher-type kilns have been used as continuous furnaces that have high productivity. In the pusher-type kiln, high-strength refractory plates, on which cores to be sintered are placed, are pushed in from the inlet with the aid of oil cylinders. Although precise atmosphere control is possible, the furnace length is limited by the limitations of the strength of the plates, moreover, the sintering time is very long, taking up to one day or so.

In the roller hearth kiln, light-weight plates travel on rotating rollers made of ceramics. Although this type of kiln has a large production capacity, it has been said to be unsuitable for the sintering of MnZn ferrite, which requires precise control of temperature and oxygen concentration in the kiln atmosphere.

Hence, Kawasaki Steel, in conjunction with Kawatetsu Ferrite Corp., developed a new roller hearth kiln that provides both high quality MnZn ferrite and high productivity[8,9], and obtained the following performance and product characteristics.

(1) The sintering time of the newly-developed precisely atmosphere-controlled roller hearth kiln is 11 h-half the sintering time requited with the conventional pusher-type kiln.

(2) The production capacity per kiln has increased from the conventional tonnage of 70 t/month to 100 t/month.

(3) It has become possible to simultaneously sinter two types of MnZn ferrite materials, i.e., low-loss materials and high-permeability materials, without a changeover of sintering conditions.

(4) In a mass production process in which the latest roller hearth kiln was used, a low core loss of P_{cv} = 270 kW/m^3 (100 kHz, 200 mT, 95°C) was achieved in the low-loss material MB4 and an initial permeability μ_i/μ_0 = 10 000 was achieved at frequencies up to 100 kHz in the high-permeability material MA100.

5 Concluding Remarks

More than ten years have passed since Kawasaki Steel decided to move into the soft ferrite business. This paper has described the research and development carried out during that time. The company intends to develop materials that can meet demand for even lower losses, higher permeability and higher frequencies and supply them through Kawatetsu Ferrite Corp. and Kawatetsu Ferrite Thailand Corp., which are the production and marketing departments of the company.

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