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Development of the Atmosphere Controlled Roller Hearth Type Kiln for High Performance Mn-Zn Ferrites*



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1 Introduction

The Mizushima Factory of Kawatetsu Magnex Corp. (Kawatetsu Ferrite Corp. at present) started producing soft magnetic Mn-Zn ferrite cores in the Mizushima Works of Kawasaki Steel in October 1990. The manufacturing of Mn-Zn ferrite cores is a part of the new business development at Kawasaki Steel. Kawatetsu Ferrite Corp. (KFC) conducts integrated production to ferrite cores from a main material, the high-purity iron oxide, which is manufactured in the Mizushima Works of Kawasaki Steel. The market for Mn-Zn ferrite has grown rapidly because of the increase in small, thin and high-frequency types of electronic equipment such as power supply transformers and noise filters. KFC's mass production has continuously increased with market growth, reaching 240 t/month now.

Mn-Zn ferrite is an oxide ceramic with excellent magnetic properties. KFC offers two main types of material; one acts as a low power loss material in electric power supplies and the other is of high initial permeability.

When manufacturing Mn-Zn ferrites, sintering influences the magnetic properties of the products the most. The initial permeability (μ_i) and power loss (P_{cv}), especially, are quite sensitive to the temperature and the oxygen content throughout the sintering process. On the other hand, as well as better performance, higher productivity is also required in the sintering process which determines the manufacturing capacity of Mn-Zn ferrite.

Three types of kiln are commonly used for Mn-Zn ferrites: the batch kiln (BK), continuous pusher kiln (PK), and continuous roller hearth kiln (RHK)[1]. The BK allows a batch of cores to occupy the kiln at a constant capacity. Sintering undergoes a fixed pattern of temperature and atmospheric changes. The cores are then removed after cooling. The sintering conditions of the BK can be controlled precisely and changed for each batch. The PK and RHK are continuous furnaces in which ferrite cores are sintered on refractory plates, passing through furnace tunnels at a constant speed under fixed temperature and the atmospheric conditions. As for the RK, ferrite cores are transported on high-strength refractory plates which are pushed starting from the entrance of the kiln by means of high-power oil cylinders. The maximum length of the RK is about 30 m because the refractory plate has a limited strength to endure this pushing pressure. Electric heaters are used

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during the entire heating and sintering. With both the entrance and the exit sealed by double doors. This is to decrease the oxygen content to only a few ppm during cooling. The RHK transportation method, generally used for manufacturing pottery, uses light refractory plates and rotating ceramic rollers. The RHK, therefore, has the largest production capacity. But the RHK hardly allows the control of the sintering conditions, particularly the oxygen concentration, because it is directly heated by gas (e.g. LPG), and has no closed type entrance and exit. The BK and/or PK are therefore usually used for high-quality Mn-Zn ferrites[1]. But these types of kiln have reached full production capacity at about 70 t/month.

KFC and Kawasaki Steel have developed three RHKs at the KFC Mizushima Factory. The third one serves to produce high quality and high productivity in the mass production of Mn-Zn ferrites.[2,3]

The newly developed RHK and the characteristics of its products are described in this paper.

2 Atmosphere Controlled RHK

2.1 The Short History of Development of the RHK at KFC

KFC and Kawasaki Steel, as mentioned previously, have constructed three RHKs and a PK. Their specifications and capabilities are shown in **Table 1**. The first RHK was introduced in December 1989 as a test furnace to search for possibilities. The first RHK allowed the accumulation of basic data and precise temperature and atmosphere control methods to be developed. The PK was introduced as the second furnace in March 1990 when production began. The next RHK was the third furnace made in May 1991 based on the technologies and mass produced at this time. The third furnace has a simple structure of a tunnel furnace in comparison to the PK, so that few troubles arise in this machine and system. The third furnace has a production capacity of 70 t/month, which is four times that of the first RHK. As for the magnetic properties of Mn-Zn ferrite cores, the initial permeablility (μ_i) of high-μ_i materials is not able to surpass that of the PK which sinters materials simultaneously with low-P_{cv} materials.

The new RHK (the fourth) was developed in May 1994, for the purpose of improving the magnetic properties of Mn-Zn ferrite. The high-μ_i materials from the new RHK have the relative permeability (μ_i/μ_0 : μ_0 is the permeability of free space) that exceeds the value 7 000, and the low-P_{cv} materials can be sintered simultaneously. The total sintering time of the new RHK is reduced to less than 11 h, which is less than half the time needed by the PK. The production capacity in this RHK (50 m long) is thus 100 t/month.[4]

2.2 The Structures and Characteristics of the New RHK

The kiln is divided into the four zones as shown in **Fig. 1.** (1) Total decarbonization occurs during the pre-sintering phase of the first zone so that the cores can be sintered more rapidly afterward. This zone is 10 m long and is separated from the sintering kiln so that no organic gases flow from the binder into the next zone. With pre-sintering very large cores e.g. R128 (ring core: OD = 128, ID = 96, H = 30 mm, weight = 850 g) can be sintered. (2) In the heating-up zone, direct-gas-firing from both above and beneath the refractory plates increases the heating rate. During testing, the maximum heating rate reached 1 800°C/h. **Figure 2** compares the heating of the RHK to the PK. It takes about 3 h for the RHK to reach its maximum temperature, less than half of the time needed by the PK. (3) In the 3rd zone of the kiln, the maximum sintering temperature is maintained for a relatively long time, resulting in shorter heating and cooling zones, in spite of the short overall sintering period. In the RHK, the 3rd zone is 24% of the total sintering cycle, which is larger than that of the PK; 13%.

The relation of the magnetic properties of Mn-Zn ferrites to the holding time at maximum temperature is shown in **Fig. 3**. The P_{cv} of the low-P_{cv} materials is saturated for 2 h during the holding time. The μ_i/μ_0 of the high-μ_i materials increases monotonously in proportion to the holding time. Two hours of holding time is enough for both materials. (4) In the 4th zone, the cooling zone is most important for the magnetic properties of Mn-Zn ferrites because these characteristics strongly depend on the degree that the ferrites oxidize. In order to preserve the composition and the structure of the spinel's single phase, it is necessary to control the partial pressure of oxygen, Po_2, over the temperature, particu-

Table 1 Main specifications of the three RHKs and the RK in Kawatetsu Ferrite Corp.

	Start	Length of kiln (m)	Pre-sintering furnace (m)	Kiln time (h)	Productive capacity (t/month)	Loading plate (mm × mm)
RHK						
No. 1 (Prototype)	Dec., 1989	20	—	10	15	350 × 350 (1 line)
No. 3	May, 1991	40	—	11	70	350 × 350 (2 lines)
No. 4	May, 1994	40	10	11 (With pre-sintering)	100	350 × 350 (2 lines)
PK No. 2	Mar., 1990	30	10	22 (With pre-sintering)	65	340 × 340 (2 lines)

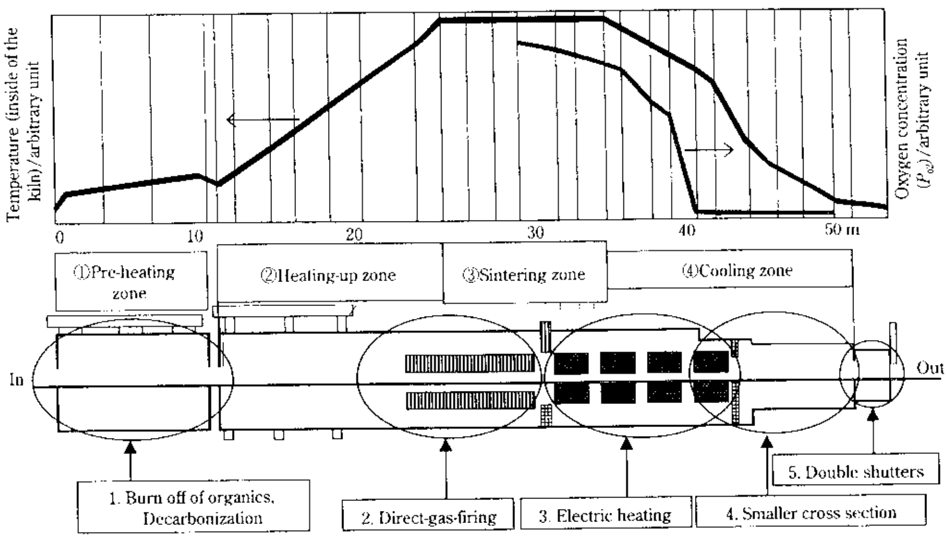

Fig. 1 The schematic view of the new RHK and the sintering conditions

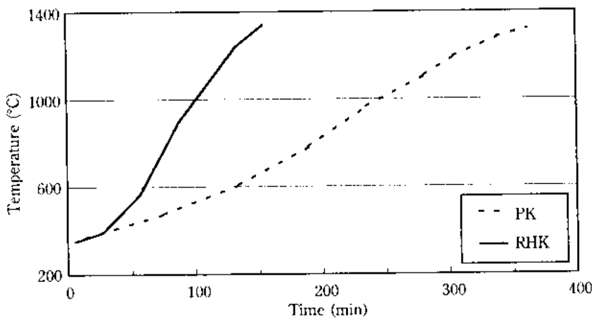

Fig. 2 The difference of the heating step between PK and RHK

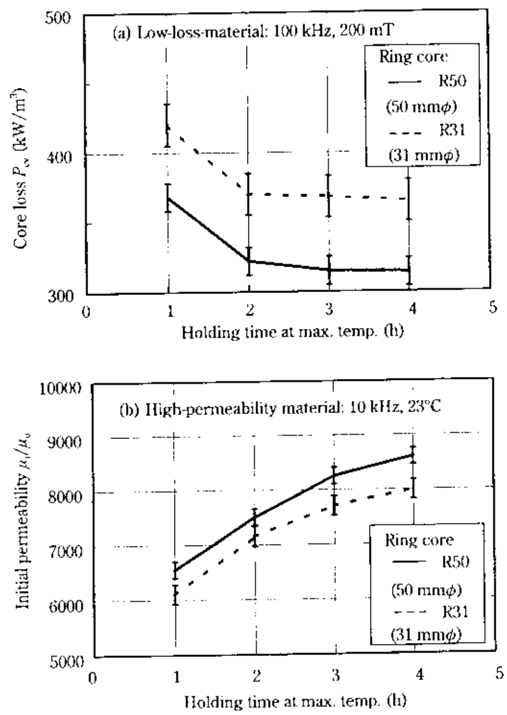

Fig. 3 Holding time dependence of the magnetic properties

larly during cooling.[5,6] The relation of Po_2 to the oxidation and temperature has already investigated this aspect. The study shows that a multiphase region exists with the spinel and the hematite at excessive oxidation levels. Under the reduction condition (lower Po_2), Mn-Zn ferrite, on the contrary, generates the wustite phase. In ferrites, the oxidation degree is often expressed by its Fe^{2+} weight percentage. It is considered that the optimum level of Fe^{2+} varies between the two materials, *i.e.*, high-μ_i and low-P_{cv} materials. Therefore, Po_2 should be precisely controlled and decreased steadily to 100 ppm or less in the latter half of cooling in order to sinter the two different materials simultaneously. Electric heating at the end of sintering controls precisely the oxygen content and temperature during sintering and subsequently cooling, as shown in Fig. 1. Electric heating makes the atmosphere more stable than direct-gas-firing does. The cross section of the cooling zone is made narrower than the other parts of the kiln. The narrow aperture at the cooling zone, as well as the double exit shutters and roller-hole seals, contributes to significantly decreasing the oxygen concentration to about 100 ppm. How the Po_2 is affected by the lapse of time is shown in **Fig. 4**. Thus the aperture optimizes the relation of temperature to oxygen content during the Mn-Zn ferrite phases. The narrow aperture at the cooling zone is able to accelerate the cooling rate. As shown in **Fig. 5**, the cooling period of the RHK is 40% shorter than that of the PK.

2.3 Magnetic Properties of Mn-Zn Ferrites Sintered by the RHK

The core loss, P_{cv} , is shown in **Fig. 6** for the lowest P_{cv} material in mass production, MB4, in comparison to the conventional low-P_{cv} material MB3. The P_{cv} of MB4

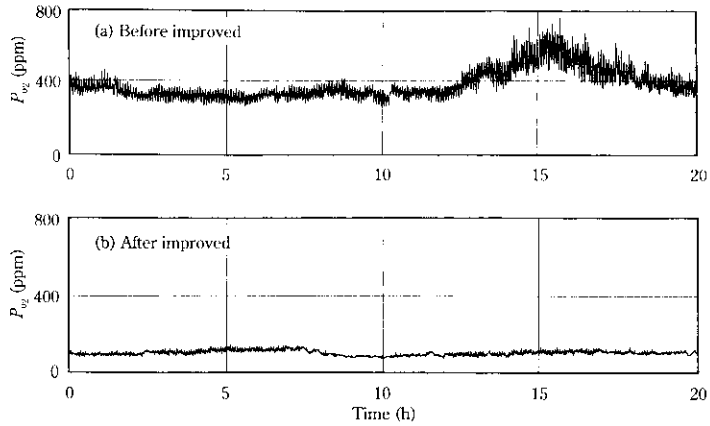

Fig. 4 Time dependece of Po_2 in the coolling zone before and after improvement

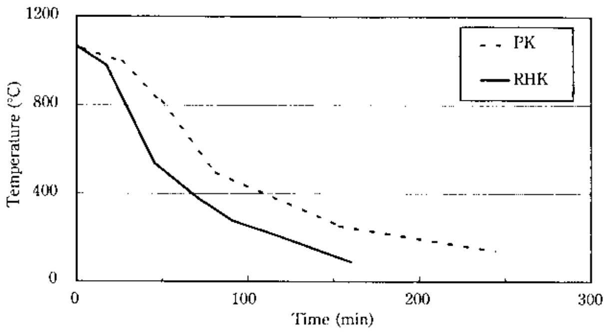

Fig. 5 The difference of the cooling step between PK and RHK

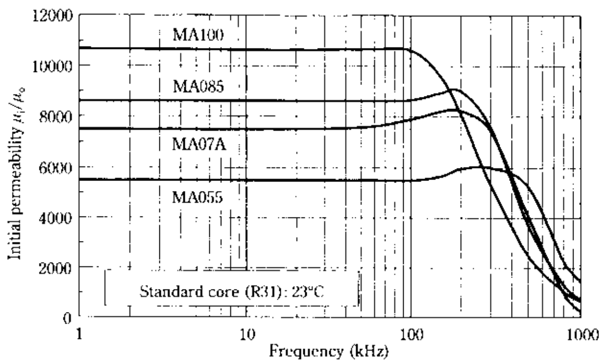

Fig. 7 Frequency dependence of the initial permeability, μ_i/μ_0, for various high-permeability materials

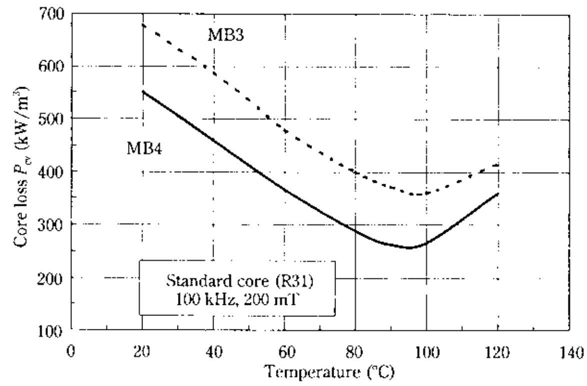

Fig. 6 Temperature dependence of the core loss, P_{cv}, for MB3 and MB4

is 270 kW · m^{-3} at the conditions of 100 kHz, 200 mT and 95°C. The initial permiability μ_i/μ_0 is shown in **Fig. 7** for various high-μ_i materials. The highest μ_i/μ_0 is 10 000 (MA100) at 23°C and is maintained up to 100 kHz. These two different types of Mn-Zn ferrite can be sintered simultaneously in the RHK, thus proving the kiln to make history in the mass production of Mn-Zn ferrites.

3 Discussion

3.1 Comparison with the PK

The merits of the newly developed RHK is dscussed in relation to the PK. In general, the most important difference between the RHK and PK is the rates of heating and cooling, which influence both the productivity and the magnetic properties of the products. For example, the μ_i value increases with an increase in the sintering density determined by the rate of heating[5,6].

The difference of the rates arises from the two reasons. One is the heat capacity of the moving refractory plates. The plate used in the PK is 5 times heavier than that in the RHK. The other is the ability of the oil-cylinders to transport the plates by pushing. The characteristics of MA100 and MB4, for example, are shown in **Table 2**. Their magnetic properties are shown to improve at a higher sintering density.

However, the problem of how to prolong the life time of the refractory plate arises through this higher heating and cooling rate in the RHK. We have been developing refractory plates that resist the stress from this rapid heat cycle.

Table 2 Magnetic properties of MA100 and MB4 compared between the RHK and the PK

	MA100		MB4	
	μ_i/μ_0*	Sintered density (kg/m^3)	Core loss P_{cv}** (kW/m^3)	Sintered density (kg/m^3)
RHK	11 020	5.04	253	4.91
PK	9 640	5.00	273	4.88

*10 kHz **100 kHz, 200 mT, 90–100°C

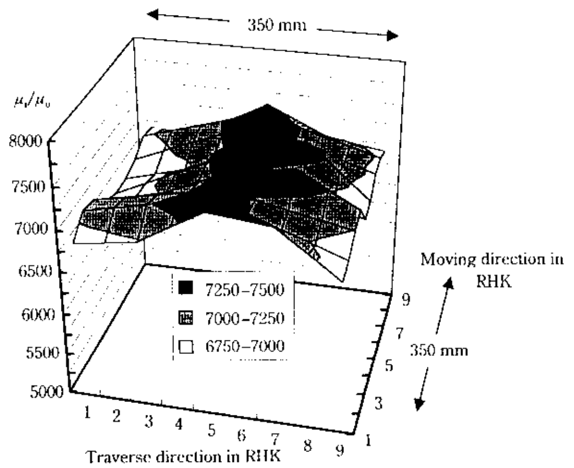

Fig. 8 Distribution of μ_i/μ_0 of MA070 on a moving refractory plate in the RHK (The dispersion of μ_i/μ_0 of cores is obtained within 5%)

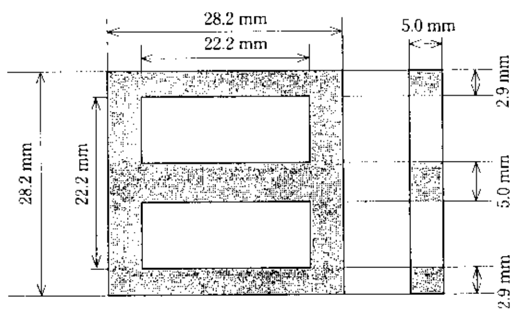

Fig. 9 The dimensions of an ET28A core

Next, the influence of location in loaded stack on a single plate on the properties of the product is described. **Figure 8** shows the distribution of the magnetic property on a single loading plate in the RHK. The product consists of ET28A cores of the high-μ_i material MA070 (**Fig. 9**), and 450 cores are arranged on a refractory plate 350 mm by 350 mm. The μ_i/μ_0 dispersion of the cores is determined within 10%. It is difficult to obtain such uniform properties in the PK, in which the dispersion is usually within 30%. There are two reasons why the uniformity is achieved. First, the direct-gas-firing method results in a large amount of gas flow. This leads to homogeneous temperatures and atmospheric distribution in the cores stacked on the refractory plates moving on ceramic rollers in the RHK. These temperatures uniformity and long sintering periods provide uniform sintering conditions and consequently electromagnetic properties of the cores. The other is the influence of the heat capacity of the core stack on the refractory plates. The heat capacity of the stack is so large in the PK that not only the temperature but also the heating and cooling rates are different between the cores at the inner and outer parts of the mounting.[4)]

3.2 Improvement of the Transportation Equipment

In mass production using the RHK, the risk of an accident from damaged roller is very serious. If an accident happens, operation should be stopped for 2 or 3 days. In order to prevent such an accident, three improvements were made. First, the materials used for the ceramic rollers in the high temperature region was changed to silicon carbide. Second, a sensor has been developed which will give a warning if only one roller is defect. Finally, the refractory plate was also reinforced against any damage incurred by the rapid heating and cooling.

4 Conclusion

The total sintering time of a new RHK is reduced to less than 11 h, which is less than half the time needed by the PK. The production capacity in this RHK (50 m long) thereby reaches 100 t/month. Two different types of Mn-Zn ferrite, i.e. high-μ_i and low-P_{cv} materials, can be sintered simultaneously in the RHK. The μ_i/μ_0 of high-μ_i material, MA100, reaches 10 000 at up to 100 kHz, and the P_{cv} value of low-P_{cv} material, MB4, is reduced to 270 kW · m^{-3} at 100 kHz, 200 mT and 95°C in mass production.

5 Acknowledgments

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References

1) E. Roess: "Modern Technology for Modern Ferrites", Proc. of ICF-5 India, (1989) 129–136.
2) Kawasaki Steel Corp.: Jpn. Koukoku 4–77234
3) Kawasaki Steel Corp.: Jpn. Koukoku 6–76257
4) S. Kijima, K. Arie, K. Gotoh, S. Nakashma, H. Kobiki, T. Kawano, N. Soga, and S. Gotoh: J. Phys. IV France, (1997) Colloque C1, 65–66 (ICF-7 Bordeaux, Sep. (1996))
5) T. Hiraga, K. Okutani, and T. Oshima: "Ferrite", 56–63, (1998)
6) K. Okutani, "Development of the Low Power Loss Ferrite for Switching Power Supply" 4th-ICF, San Francisco, (1984)