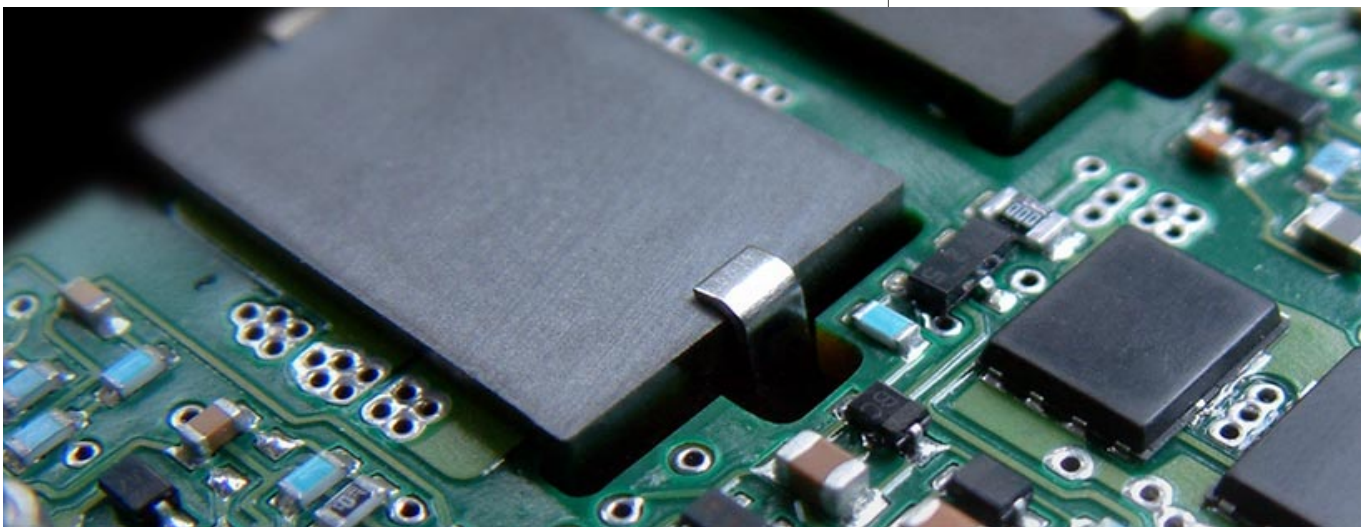
Low-loss/High Saturation Magnetic Flux Density Ferrite For Power Transformers Supporting Wide Temperature Range

PC95 Material

Conforming to RoHS Directive

Conformity to RoHS Directive: This means that, in conformity with EU Directive 2002/95/EC, lead, cadmium, mercury, hexavalent chromium, and specific bromine-based flame retardants, PBB and PBDE, have not been used, except for exempted applications.



Product Features

This most-advanced mangan-zinc-type power ferrite realizes industry-leading low-loss/high saturation characteristics over a wide temperature range between -40 and +120°C for downsizing and low energy consumption of diverse power units and circuits.

A new controlling realm of core-loss vs. temperature characteristic was developed.
Fuel-efficiency, electric-power saving, downsizing and weight-saving will be enhanced.

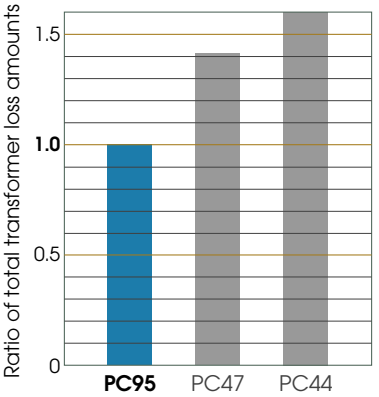
The advantages of the PC95 material, which is able to elicit full potential of the transformer over a wide temperature range, offer great merits in saving electric-power of the DC-DC converters of hybrid cars (HEV), electric vehicles (EV), and fuel cell vehicles (FCEV); large-screen LCD televisions and projection devices with many built-in inverter transformers for the back light; and routers and network switches, which facilitate high-speed large-capacity IP communications; as well as weight-saving/down-sizing of all these devices.

As a simple example, on the right is a graph of total transformer loss amount ratio where the two types of conventional ferrite material and the PC95 material are applied respectively as a main transformer of a DC-DC converter for electric vehicles.

Comparing the simulation results, with consideration to the changes in temperature and other conditions where an electric vehicle is driven for one year, we discovered that the total loss of the main transformer for the DC-DC converter can be reduced by about 30–40% if the PC95 material is uses. Without having to convert into fuel efficiency, the saving of electric power and resources by the PC95 material has reached a level that goes far beyond the conventional materials.

Comparison of total transformer loss amounts

A comparison was made on the total transformer loss amounts* where the PC95 material is used for the main transformer's core of electric vehicle's DC-DC converter and where other materials (PC47 and PC44), based on the PC95 material.

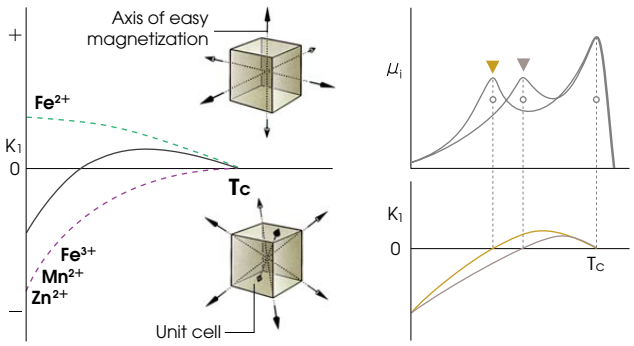


*Total transformer loss amount: derived from simulation of change in operating temperature of the DC-DC converter's main transformer compatible with vehicle's driving environment change (driving period: one year).

Responding to ever-sophisticated low-loss power source demands

The conventional method controlling transformer's loss characteristic depending on application's heat conditions

The conventional loss reduction method took advantage of the characteristic that the both positive and negative crystal magnetic anisotropy constant K_1 (the height of the energy barrier standing between the axis of easy magnetization = the greater this values is, the less susceptive to magnetization) of the unit cell, the minimum magnetization mechanism which constitutes ferrite, becomes smaller as the temperature rises (heat disturbance effect). By controlling the amount of metal ion, which mostly represents positive K_1, the offset temperature* of the both positive and negative K_1 was set at the optimal value depending on diverse power supply circuits.



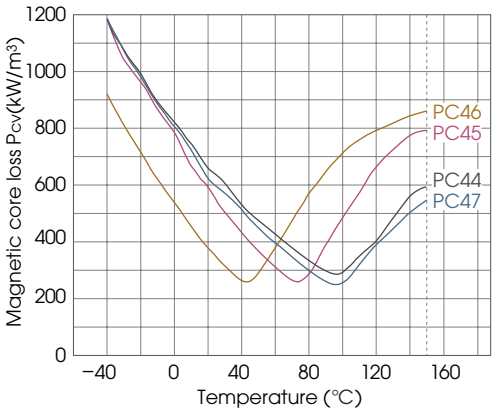
*K_1 can be an energy barrier that interferes magnetic moment's directional change (ie, magnetic wall movement) caused by external magnetic field. But at the temperature where K_1 is 0, the magnetic wall can travel extensively, and therefore the value of the initial permeability μ_i, which represents the traveled width of the wall per unit magnetic field, reaches its peak and the loss marks its lowest level.

Aside from transformers, the temperatures of power supply circuits can rise due to the heat of the components with diverse loss factors. But by setting the temperature where the K_1 of ferrite material hits zero a little higher than the highest temperature of the entire power supply circuit during uninterrupted operation, the transformer can be operable in the temperature range where the magnetic core loss is the lowest level. This also prevents heat crash when the transformer's environmental temperature, for some reasons, rises, unless the temperature where K_1, set slightly higher, reaches zero (ie. the minimum loss) is exceeded.

For example, the power ferrite PC44 material and the PC47 material, a modification of PC44 realiz-ing the industry lowest level loss characteristic, have their temperature where the magnetic core loss is the lowest (where K_1 is zero) set around 100°C. Also, the PC46 material with the lowest magnetic core loss set around 40°C was developed for the DC-AC inverters used as backlighting of LCD displays.

In terms of the fact that the transformer is operable in the lowest magnetic core loss range, these conventional methods, which optimize the physicality of the power ferrite material depending on the application, has been contributing in powersaving of household electrical appliance, for which temperature rising and the highest reachable temperature can be predefined.

Core loss vs. temperature characteristic of conventional materials



Increased demands for support for wide temperature range and low-loss power supplies

However, power supply applications, for which the method is not fully effective, have emerged in recent years, namely, HEV (Hybrid Electric Vehicle), EV (Electric Vehicle), and FCEV (Fuel Cell Electric Vehicle).

DC-DC converter for HEV, EV, and FCEV
Efficiently converts main battery's high voltage into a low voltage before supplying it to diverse electric equipment.

Of course, efforts have been put in streamlining and downsizing/weigh-saving of power supply circuits since the early stage as essential technical tasks. But for the DC-DC converter, which is the gist of the power system, design consideration for keeping the loss at a low level throughout a wide temperature range is essential because the thermal conditions can change drastically

Development of new controlling method of core loss vs. temperature characteristics

due to increase/decrease of the load as well as the changes in the environmental temperature while driving.

Also, in the field of audio/visual devices, the screen sizes of LCD TVs and LCD displaying devices has been rapidly enlarged. On the back of these large LCD displays, there are a large number of cold-cathode tubes for backlighting and inverter circuits for lighting. Since the heat radiation efficiency differs depending on the installed location, the maximum temperature has a gradient. For that, with the conventional materials aimed at certain temperatures, designing for comprehensive and thorough power saving and low loss characteristic has been difficult.

Embedded power supply applications with such temperature gradient include IP service routers and network switches of the information technology field.

With the drastic evolution and accelerated processing speeds of MPUs, network processors, memory controllers, and so forth, multistaged rack devices of 400W or 500W have become common. Exhausting heat by forced air cooling of each rack with a power supply circuit is not enough to cancel the temperature gradient occurring in the center and on the sides. For these distributed power supply systems, further streamlining and making it low heat-generation seems to be increasingly important tasks in the future with ever-increasing electric power consumption.

Our efforts toward "low core-loss flattening technology" which exceeds the limits of the conventional K1 controls

In order to respond to these extremely increasing needs for power supply, it is essential to develop a new ferrite physicality control method which will drastically alter the temperature dependency of magnetic core loss, which has been said to be the fate of ferrite physicality.

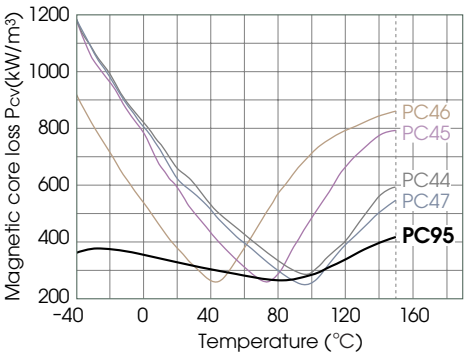
In that regard, the PC95 material, which has cleared the requirements, belongs to a new material area which goes beyond the existing PC series materials.

Underlying magnetic core loss

The "uniqueness" of the physicality outstands when the characteristic line of the PC95 material is added to the magnetic core loss-temperature characteristic data of the conventional materials.

While the characteristic lines of the conventional materials (PC44, PC45, PC46, and PC47), for which the temperature where the magnetic core loss is the smallest are controlled depending on diverse application, draw deep valleys, those of the PC95 material occupy the low loss area of 350 kW/m³ or lower between 25 and 120 °C, as if lying down. It exceeds the performance of the PC44 material in all temperature ranges, reaching 280 kW/m³ at 80 °C, which is even smaller than the existing smallest magnetic core loss of the PC47 material. It was not a mere expansion of low-loss temperature ranges from a point to a line, it also keeps the loss at the industry's lowest level. That's where PC95's superb utility and readiness to the latest needs lie.

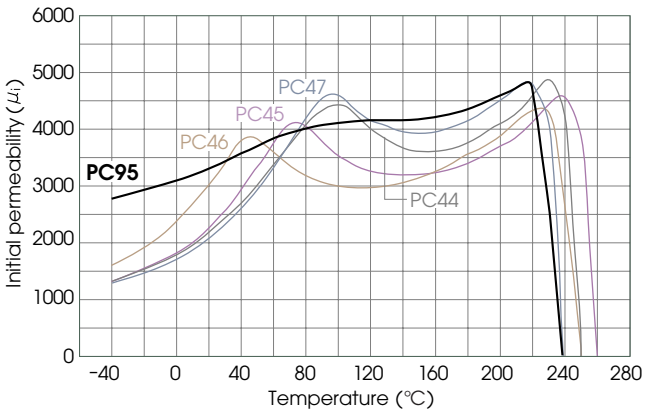
Core loss vs. temperature characteristic



Improved initial permeability

The temperature where the initial permeability μ_i reaches maximum, which is a barometer of the response performance against the external magnetic field (the alternating current superimposed on the primary coil of the transformer), is, as mentioned earlier, the point where K_1 becomes zero. In other words, it's same as the temperature where the magnetic core loss is the smallest. But once the temperature changes, the initial permeability of the conventional material decreases. As shown in the initial permeability-temperature characteristic comparison data below, the initial permeability of the PC95 material draws a stretching curve all through a wide temperature range, showing that the temperature dependency of the permeability is also small as well as the magnetic core loss characteristic.

Initial permeability vs. temperature characteristic

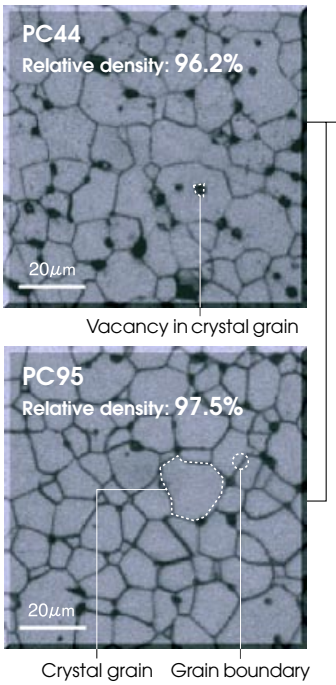


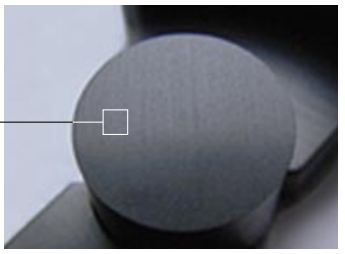
Development of new controlling method of core loss vs. temperature characteristics

Revolution of composition and strict control of fine structures

The two comparison data with the conventional materials suggest that the crystal magnetic anisotropy constant K_1 is reduced in a wide temperature range. As shown in the model diagram where $K_1 = 0$ is achieved by controlling the negative and positive of K_1, the conventional materials used a method in which diatomic ferric iron Fe^{2+} was controlled when controlling K_1. But for the PC95 material, a new K_1 controlling method was developed to introduce the fourth metallic ion showing positive crystal magnetic anisotropy constant K_1 as well as main components such as iron, mangan, and zinc. A production method that keeps K_1 at a low level throughout a wide temperature range while maintaining stable industrial production was established.

In addition to these efforts, improvements were made in the entire mass-production steps such as advanced equalization of starting materials, precision control of minute additives, reexamination of sintering process, and so forth, seeking generation conditions for ideal crystal grain boundary structure of mangan-zinc ferrite and realizing high-density crystal grain with drastically reduced vacancies and lattice defects.



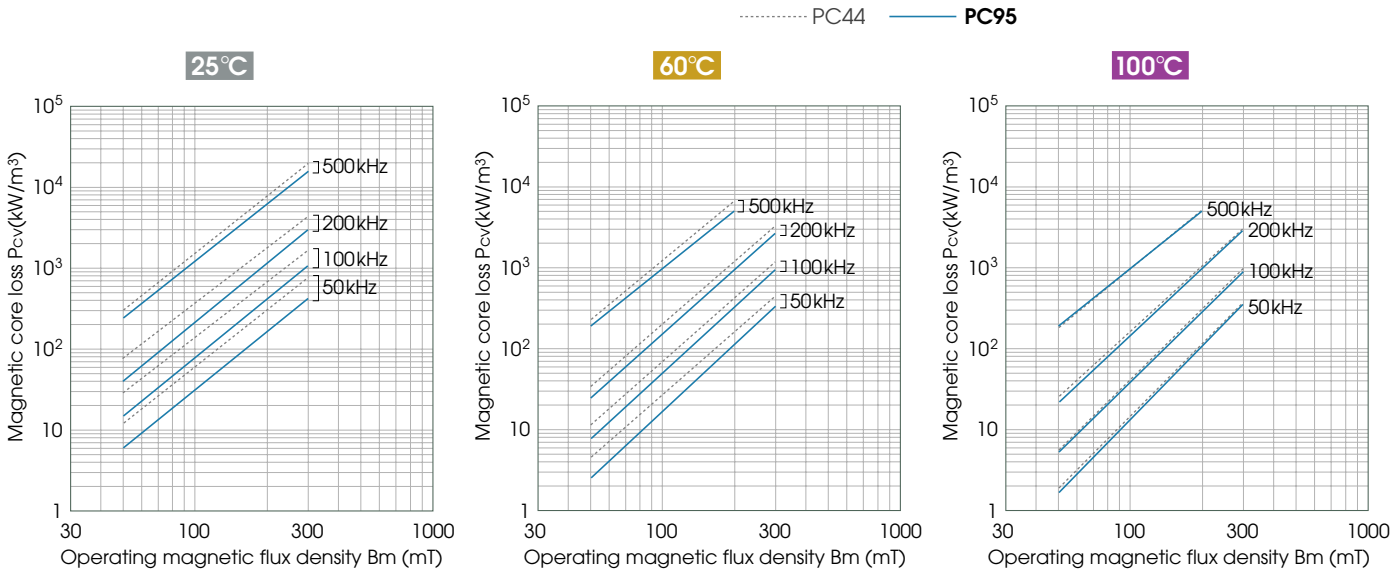


Comparison of crystal fine structures

Through examination of cation concentration which constitutes the spinel grating and precise control of sintering process, high density minute crystal grains with minimum vacancy creation and uniformed high-resistance grain boundary were realized. Low-loss performance that exceeds the limitations of that of the conventional materials and high-level saturation magnetic flux density were achieved.

Magnetic core loss vs. operating magnetic flux density characteristic

As an overall achievement of the efforts, hysteresis loss and eddy-current loss, which are more than half of all magnetic core loss factors, were successfully reduced by a large margin (Please refer to the graph chart below for the relationship among frequency, operating magnetic flux, and magnetic core loss). In the frequency bands under 100kHz, the magnetic core loss is separated into hysteresis loss in proportion to the frequency and eddy-current loss in proportion to the square of the frequency. But the loss of PC95 material is lower than the PC44 under all measurement conditions of the graph chart and both the hysteresis loss and eddy-current loss are reduced.



Example of standard shape / Comparison of material characteristic

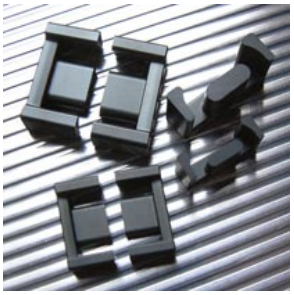
Shapes and dimensions
(Standard shape example)

The product lineup includes the PQ, ELT, and EPC series with ideal core shapes and sizes for diverse applications.
Non-standard shapes are also available upon request. Please feel free to contact us for details.

PQ type

Core for built-in DC-DC converter's main transformer for HEV, EV, and FCEV

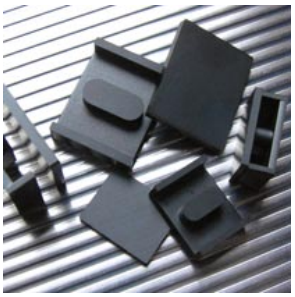
Example of core shape (one pair) L35×W26×T35mm / L41×W28×T30mm



EPC type

Core for LCD display backlight inverter transformer

Example of core shape (one pair) L20×W19×T6mm / L35×W30×T8mm



ELT type

For brick power source for communication devices, low-profile DC-DC converter

Example of core shape (one pair) L16×W12×T4mm / L22×W18×T8mm

Comparison of material characteristics

Material name			**PC95**	PC47	PC44
Initial permeability*1 μ_i		(at 25°C)	3300±25%	2500±25%	2400±25%
Core loss volume density*2 P_{cv}	(kW/m³)	(at 25°C)	350	600	600
		(at 80°C)	280	290	320
		(at 100°C)	290	250	300
		(at 120°C)	350	360	400
Saturation magnetic flux density*3 B_s	(mT)	(at 25°C)	530	530	510
		(at 60°C)	480	480	450
		(at 100°C)	410	420	390
		(at 120°C)	380	390	350
Residual magnetic flux density*3 B_r	(mT)	(at 25°C)	85	180	110
		(at 60°C)	70	100	70
		(at 100°C)	60	60	60
		(at 120°C)	55	60	55
Coercive force*3 H_c	(A/m)	(at 25°C)	9.5	13.0	13.0
		(at 60°C)	7.5	9.0	9.0
		(at 100°C)	6.5	6.0	6.5
		(at 120°C)	6.0	7.0	6.0
Curie temperature T_c	(°C)		215 min.	230 min.	215 min.
Resistivity ρ	(Ω·m)	(at 25°C)	6.0	4.0	6.5
Bulk density δ	(kg/m³)		4.9×10^3	4.9×10^3	4.8×10^3

*1. at 100kHz, 0.1A/m *2. at 100kHz, 200mT *3. at 1194A/m