Ferrite Processing & Effects on Material Performance

George E. Schaller

Ceramic Magnetics, Inc.16 Law Drive, Fairfield, NJ

Introduction:

The technical demands of magnetics in modern electronics; power conversion, communications, computers, instrumentation and high energy physics requires the circuit engineer to be familiar with the manufacturing techniques of ferrites. Compositions and process steps greatly effect the magnetic properties and shapes that can be generated. In order for the engineer to select the correct material and shape he should be acquainted with the chemistry and manufacturing procedures necessary to produce his required core.

With this information the engineer can select the required magnetic device to solve his circuit requirements. Modern electronics demands more sophisticated materials and geometries than are available from the standard catalogue. Can the core be pressed, injected molded, extruded, machined and will the core meet the magnetic performance required? This is the question that the engineer should consider when doing a magnetic design.

The composition range of the standard grades of MnZn and NiZn ferrites and the effects of the various manufacturing steps on magnetic properties will be reviewed. Several of the currently used additives to improve or alter properties will be discussed.

Process Steps:

The overall processing of ferrites requires several major steps which directly effect the magnetic properties. Figure 1 shows these steps in a simple linear block diagram. These steps will be treated in three major groups. Group 1- composition - includes selection of raw materials and mixing. Group 2 - process - includes calcine, milling and drying. Group 3 - fabrication - includes forming, sintering, machining and test.

Manufacture of Ferrite Cores
Composition
Process
Fabrication

Each of these major steps and the effects on the core properties will be discussed.

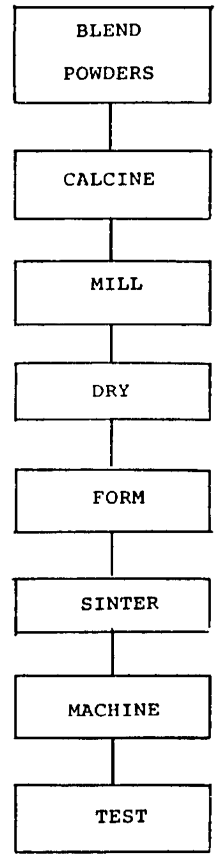


Fig. 1 Diagram of Process Steps

The current improvements in efficiency of power ferrites and increases in permeability is a result of closer composition and process control coupled with selective use of additive to control resistivity, grain size and losses internal to the grain. Improved manufacturing process controls and impurities in raw materials has led to the available of 15,000 permeability toroids with acceptable temperature properties. In addition the advances in solid state devices for RF power transmission has led to the requirement for improved NiZn material for impedance matching and coupling transformers.

Compositions:

General purpose ferrite material were invented in the late 1930. These early materials were used for low level application in communications. Extensive research on compositions were conducted throughout out the 50 and 60. Most of to days information is based on this body of work. The research done during the 70 and 80 is in refinement of this early work and in process improvements.

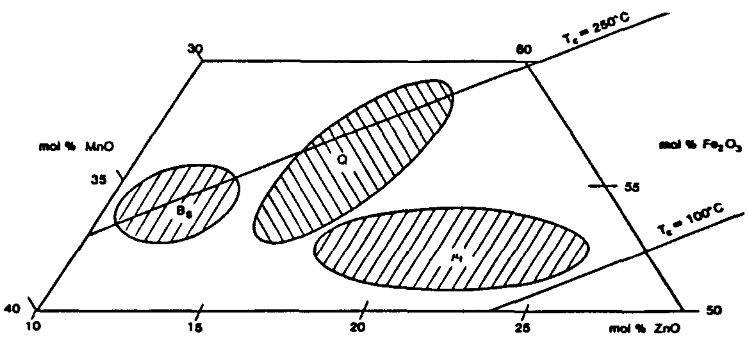


Fig. 2 Triaxial Diagram of Ferrite Compositions

The selection of raw materials is critical in controlling the overall magnetic properties. Figure 2 shows the composition diagram for MnZn ferrite. The three axes in mole percent are Fe_2O_3, ZnO and MnO. Three generalized areas are shown defining compositions associated with μ, Q and Bsat. This figure shows the range of each oxide that produces a ferrite that may have interesting properties for cores in power , communications or pulse transformers.

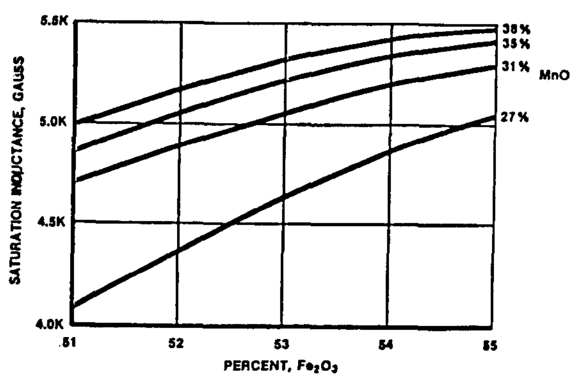


Fig. 3 Saturation Flux Density Versus Composition

Figure 3 is a graph of saturation induction for different composition. Figure 4 shows the composition effects on Curie temperature. These graphs shows that the variations of oxides for commercial materials is about 5% for Fe_2O_3 and 10% for MnO and ZnO. Figure 5 shows the composition required to achieve permeability greater than 2500. An additional point on this figure is that initial permeability decreases with higher MnO content, therefore μ greater than 5000 require MnO content less than 25%.

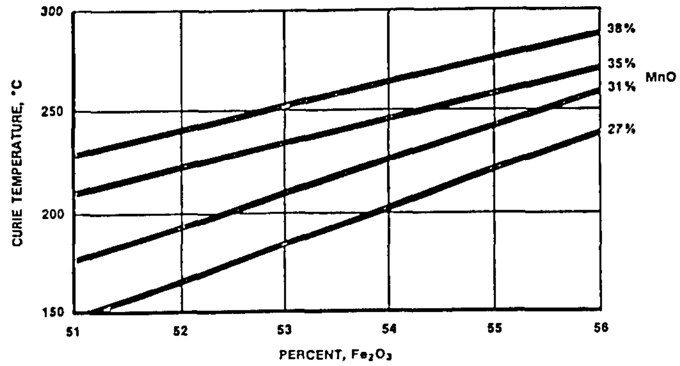


Fig. 4 Curie Temperature Versus Composition

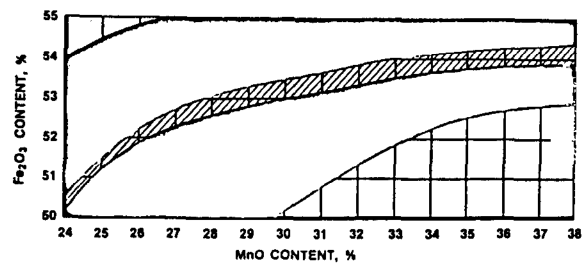


Fig. 5 Composition Effects on Permeability
$\mu > 2000$ and $\mu > 2500$

Figure 6 shows the effects of temperature on initial permeability. The permeability peak at about 10°C is dependent on the Fe_2O_3 content. It will move about $\pm$ 1°C for $\pm$ 0.1% Fe_2O_3 variations.

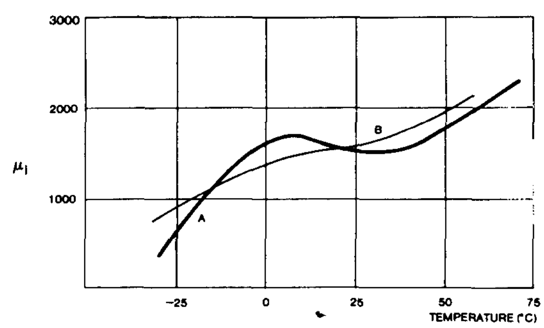


Fig. 6 Core μ Versus Temperature

The typical oxides used in the compositioning of a MnZn ferrite are shown in table 1.

Table 1
Typical Raw Materials

Fe_2O_3	ZnO	$MnCO_3$
99.5%	99.7%	43%
+	+	+
SiO2	PbO	Hcl
CaO	CdO	Cl

Na	Cu	SO4
Mn	Mn	Pb
Al2O3	Fe	Fe
Cu	SO3	Zn
Zn	Na	Cao
MgO	Hcl	Na2O

In addition one must also be concerned with the pH, partial size, specific gravity and surface area of the oxides.

Inspection of the purity of each oxide indicates that one must offset purity to price. Each of the listed impurities will effect the sintering behavior of the core and the magnetic performance, such as causing the core to crack or the location of the impurity in the crystal or the grain boundary. Certain impurities will cause accelerated grain growth or retard grain growth. In some cases these "impurities" may be added to utilize the positive effect they have on the required properties of the core. Several additives might include oxides Ca, Si, Cu, Ti and Co.

The second step in creating a composition in mixing these powders to assure uniform homogeneous blending. There are several techniques including high energy wet mixing, ball mill or turbine mill, or robust dry mixing. These powders are extremely fine and in some cases the weight differences may cause gradients during this mixing process.

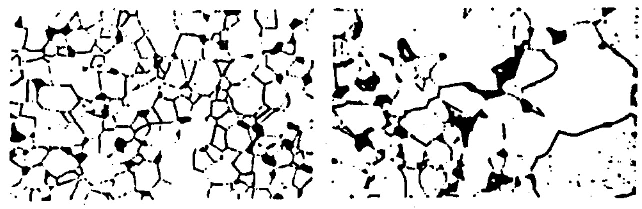
Process:

The three steps included in processing the composition are calcining, milling and spray drying.

In the calcining step one is accomplishing two changes to the blended oxides. First a spinel crystallin structure is obtained and second the shrinkage properties of the final core geometry are controlled. Typical shrinkage of an uncalcined core may be 50% on a linear side versus 15 to 20 % for calcined powder.

Calcine temperatures are typically 1000°C. The process is done in a rotating tube furnace, pusher kiln or periodic furnace. The size of the batch and required magnetics may influence the selection of the furnace. The output of this step is a course powder, consistency of a sand or small pellets.

To prepare this powder for pressing it must be ground to an average partial size of about 1 μm. To accomplish this the powder is milled in a ball mill with steel balls. Time required is dependent on the hardness of the pellets, calcine temperature, and on the desired reactivity of the powder during the sintering step. Figure 7 shows the grain size of a power ferrite milled differently. Note the uniform grain size compared to an erratic exceedingly large grains for the over milled material. The blacks spots in this figure represent porosity or grain pullouts during sample preparation.



Normal Mill PL = 740 mw/cc. 2 Hours Excess PL = 1400 mw/cc.

Fig. 7 Milling Effects on Grain Size and Power Loss

During the milling the steel ball will wear increasing the Fe_2O_3 content of the powder. This is in the range of 0.1%. In a controlled process this is allowed for in the batching step. In addition to Fe_2O_3 pick up from the mill additive can be introduced to the powder .

After milling the composition can be measured by X-ray and if necessary adjustments can be made by adding required oxides. Another technique is to create a finish core, do necessary testing, then adjust by adding oxides. This step is slow but can be more accurate in controlling high quality finished magnetics.

The last step in processing is to prepare the powder for pressing by spray drying. Binder and a lubricant is added to the powder water slurry. This slurry is then forced under pressure into a heated chamber, spray drier. This creates spherical partials, 75 μm diameter, which allows the powder to flow. Variations in the finished magnetics and geometry can be related to the partial size.

The characteristics of the spray dried powder effect the pressing properties of the core, tool wear, die fill and pressed density.

Fabrication:

There are several techniques available to forming a finished core.

Forming Techniques:

- Grinding
- Extrusion
- Pressing
- Injection Molding

Each of these forming techniques have advantages in cost, tolerances and lead times.

By far the most common forming technique is dry pressing. In this step the powder flows into a die cavity, then compacted with upper and lower punches at about 10 tons per surface square inch. Since this pressing is being done in a vertical direction the geometries are limited to simple geometric shapes. Tooling can be designed with multiple levels. Core geometries such as toroids, E / I and pot cores can be produced. It is possible to coin features into the surface of a core while pressing, however this will create density gradients. These features should be limited in depth.

The length of the core is limited to about 2" maximum. The required press stroke per 1" of length of finished core can be calculated with the following assumptions, approximately 3 to 1 powder compaction and 15% sintered shrinkage, or about 3.5" of die fill.

Grinding is the most economical forming technique to produce non standard cores. It requires no tooling since cores are ground from isostatically formed sintered bars. This allows for tolerance on mechanical dimension of ± 0.005 or better if required. It also allows for tighter control of magnetics properties.

Extrusion is an ideal technique for forming long rods and bars.

Injection molding allows the forming of complex geometries.

Tooling cost for these two techniques is generally expensive and unless production quantities are large grinding may be a cost effective solution.

Sintering is the step where everything is brought together. The final magnetic and mechanical properties are achieved. The three major parameters in sintering are time, temperature and atmosphere. Depending on the furnace used and the size of the finished part time can be less than one day in a pusher kiln for cores less than one pound to 14 days for large isostatic blocks in excess of 50 pounds. Temperatures range from 1100°C to 1400°C. The atmosphere will vary from 21% to 0% for oxygen. See figure 8 for typical cycle.

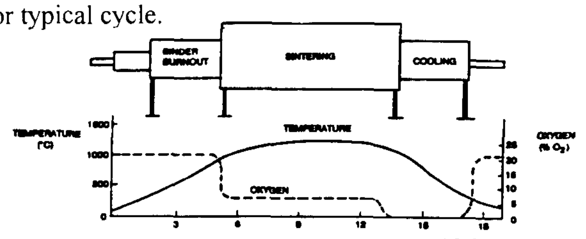


Fig. 8 Typical Firing Cycle

The several major properties controlled by sintering are:

- Final core physical density
- Saturation flux density
- Mechanical dimensions / tolerance
- Microstructure
- Power loss
- Permeability

During the sintering of MnZn ferrite cores it is necessary to control to atmosphere to balance the O_2 content to enhance the required magnetic property.

The final testing is where it is determined if we were lucky and obtained a shippable core. There is little that can be done to save a non conforming core. Occasionally cores can be annealed or resinter to improve permeability or reduce stresses.

Conclusion:

The fabrication of a ferrite core is a complex process of several dependent process steps which flow in a linear manner. There are few places where the process can be altered to adjust for normal process variations. The composition can be adjusted after milling and by fine tunning the sintering cycle certain properties can be improved. The further away from the ideal process the less likely that the finished ferrite will be useable.

With all of this said the understanding of these effects on the finished core performance is well understood. As the industry continues to improve the processing technology of ferrites coupled with further understanding of additives and impurities, then it is expected that better ferrites for more demanding applications will be available.

The engineer who uses ferrites should not hesitate to make his requirements known to the suppliers and not settle for what is in the catalogue.

References:

Soft Ferrites "A User's Guide"
Magnetic Materials Producers Association, Evanston, IL

Soft Ferrites, Properties and Applications, 2 nd Edition 1988
Snelling, E. C. Butterworth, Boston, MA