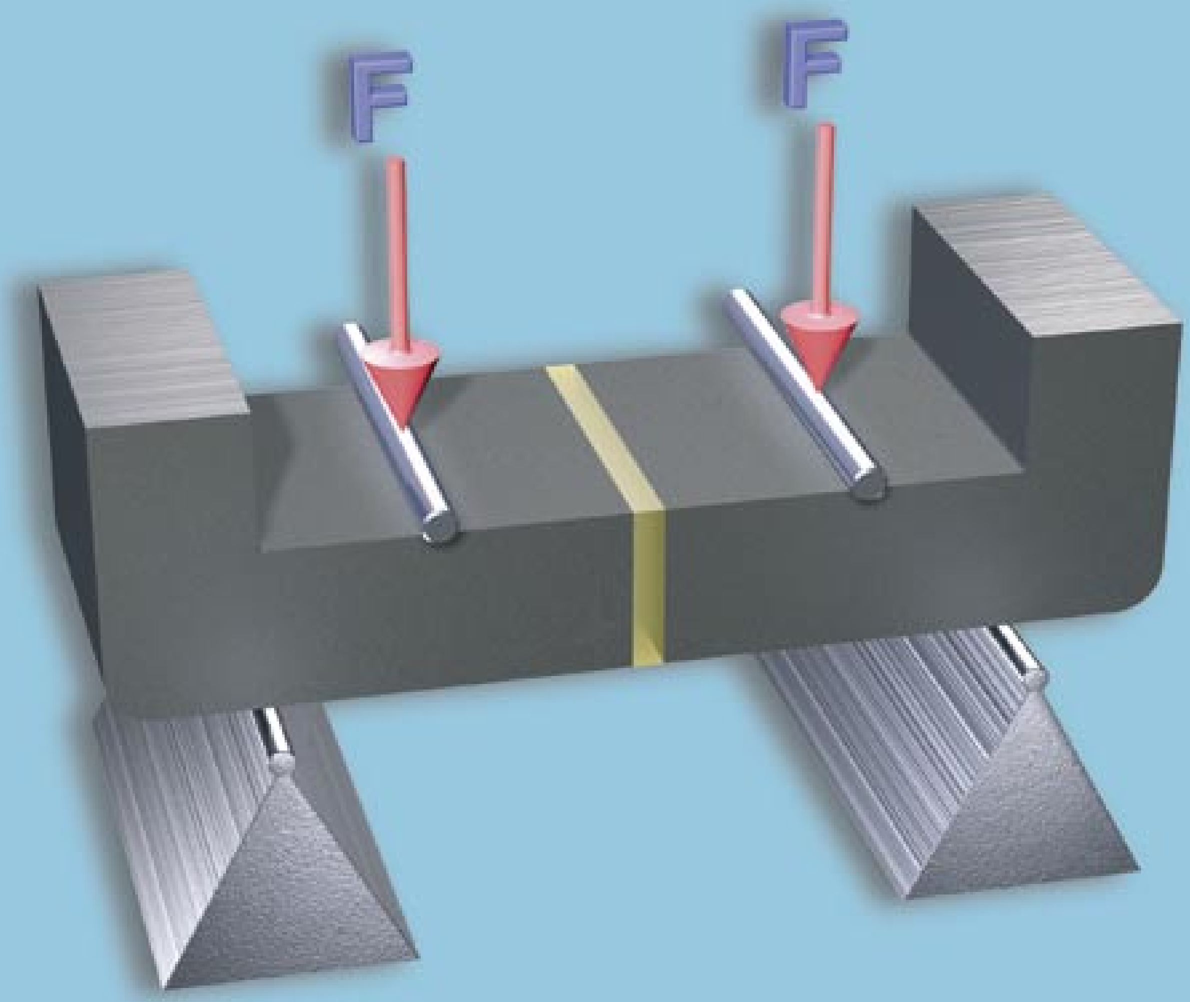
Gluing of Ferrite Cores

Application Note



FERROXCUBE
A YAGEO COMPANY

Gluing of ferrite cores

Summary

A pre-selection of 23 glues was made, based on recommendations of suppliers. Requirements to be met included good adhesion to the ferrite surface, worldwide availability, stability at a continuous usage up to 150 °C and minimal degradation during (cyclic) temperature and/or moisture tests. In view of the large variation in production practices, it is not possible to identify a general minimal required strength level for core processing and/or core operation. Comparative measurements were therefore performed. The best adhesive systems before and after the ageing tests were: Eccobond 2332-17, Eccobond 50248-F15, Threebond 2273, 3M DP-490, and Hysol RE2039 +HD0243. This conclusion does not disqualify other glues, however. Other aspects not taken into account during this study can also be very important for the final selection - for example, whether the glue is a one- or two-component type, its suitability for the assembly process, required curing conditions (short/long time at room/elevated temperature), importance of moisture resistance and cost.

Contents

A selection of glues

Gluing of ferrite cores

The gluing of mated core halves is an important step in the fabrication of inductive components such as transformers. Recent studies revealed the impact of the physical properties of the glue (e.g. modulus of elasticity and glass transition temperature) on the level of thermally induced stresses during temperature cycling tests (Refs 1 and 2). The glue-related effects were found to be minimal during normal electrical operation (Refs 1 and 2) and during surface-mount processing steps such as reflow soldering (Ref.3).

Several factors determine the choice of glue. Two of the most important are the initial bonding strength of the adhesive-ferrite interface and the preferred industrial processing conditions, e.g. whether one- or two-component glue is used, type of mixing and dosage equipment, curing time and/or temperature. Finally, the requirements for bonding strength after (cyclic) ageing tests at elevated temperature and/or high-humidity conditions can also determine the final choice of the adhesive system.

Until now, however, little information was available on the relative strengths of the glues used and on their behaviour after (cyclic) ageing tests under elevated temperature and moisture conditions.

This study has been limited to the bonding of core outer-legs with a glue layer thickness of <10 μm. This process step is often used as the initial fixation of the assembly, possibly in combination with external clamping of the core halves. The requirements e.g. physical properties, processing conditions and bonding strength for an airgap filling glue can be quite different.

Materials

The gluing experiments were performed with E42/21/15 cores made of 3C94 ferrite. The centre pole has an airgap of 1.0 mm and the machined surfaces of the centre/outer poles have a surface roughness typically of $R_a \approx 0.5$ μm.

The commercially available adhesive systems have been selected on the basis of requirements defined by Philips' Centre for Manufacturing Technology - Adhesives and Encapsulation Group. Requirements included:

- good adhesion to the ferrite surface and if possible also to common engineering plastics e.g. PA (polyamide), PBT (polybutyleneterephtalate) PC (polycarbonate), PF (phenolformaldehyde)
- adhesive gap 5 to 50 μm
- no degradation during continuous use at temperatures up to 150 °C
- minimal degradation after ageing tests (temperature and/or moisture)
- no hazardous properties
- worldwide availability

Only suppliers who reacted positively on our request for the supply of adhesive samples, and who fulfilled most of the requirements, have been included in the test list. Table 1 summarises the sample data.

Sample nr.	Parts	Supplier	Contact information	Type	Chemistry
1	1	DELO Industrieklebstoffe	www.delo.de	Monopox 1196	epoxy
2	1	DELO Industrieklebstoffe	www.delo.de	Monocast 6093	epoxy
3	1	Emerson & Cuming	+32 14 575611	Eccobond 2332-17	epoxy
4	1	Emerson & Cuming	+32 14 575611	Eccobond 50248F-15	epoxy
5	1	Loctite Corporation	www.loctite.com	317	acrylic
6	1	Loctite Corporation	www.loctite.com	366	acrylic
7	1	Loctite Corporation	www.loctite.com	661	acrylic
8	1	Master Bond Inc	+1 201 343 8983	Supreme 3HT	epoxy
9	1	Master Bond Inc	+1 201 343 8983	Supreme 10HTCL	epoxy
10	1	Threebond GmbH	www.threebond.de	2210	epoxy
11	1	Threebond GmbH	www.threebond.de	2273	epoxy
12	2	Vantico NV	www.vantico.com	Araldit 2012 (AW2104/HY2934)	epoxy
13	2	Vantico NV	www.vantico.com	Araldit 2011 (AW106/HV953U)	epoxy
14	1	Flying Dragons	fdico@ms17.hinet.net	Flygon K1401-11	epoxy
15	1	Flying Dragons	fdico@ms17.hinet.net	Flygon K1402	epoxy
16	1	Kuo Sen Enterprises	kso33794@ms15.hinet.net	EP399	epoxy
17	2	3M	www.mmm.com	DP-490	epoxy
18	2	3M	www.mmm.com	DP-810	acrylic
19	2	Vantico NV	www.vantico.com	Araldit EP 126	epoxy
20	1	Vantico NV	www.vantico.com	Araldit AV 119	epoxy
21	1	Nippon Pelnox	+ 81 465 74 1211	Pelnox ME-5890	epoxy
22	2	Dexter Corporation	+1 626 968 6511	Hysol RE2039 + HD0243	epoxy
23	2	Emerson & Cuming	+32 14 575611	Permabond F 246 & Initiator 5	acrylic

Viscosity [Pa.s]	Curing [time-temperature]	Remarks
290	40 mins 150C	
40	35 mins 100C	
120	20 mins 150C	
55	60 mins 100C	
4	60 mins 120C	also anaerobe & activator cure
8	60 mins 120C	also anaerobe & activator & UV cure
0.5	60 mins 60C	also anaerobe & activator & UV cure
150	10 mins 150C	
120	60 mins 120C	
6	10 mins 120C	
70	10 mins 150C	
35	2 mins 100C	Mixing ratio (weight) 100/100
45	10 mins 100C	Mixing ratio (weight) 100/80
400	30 mins 150C	
150	30 mins 150C	
210	60 mins 130C	
thixotropic	24 hrs-23C & 1 hr-80C	Mixing ratio (weight) 100 base / 50 accelerator
20	10 mins-70C	Mixing ratio (weight) 100 base / 100 accelerator
18	1 hr - 80C	100 wt% AY105-1 + 50 wt% HY 991
1,500	20 mins 160C	
50	1,5 hrs 120C	
14	2 hrs 80C + 2hrs 150C	Mixing ratio (weight) = 100/25
30	24 hrs 25C	NO MIXING: F246 on one surface + Iniator 5 at other surface.

Procedure

The 3C94 based E42/21/15 cores were received after industrial machining and ultrasonic cleaning in water. The centre pole had an airgap of 1 mm in order to prevent any contact between the centre poles during the gluing of the outer poles. The adhesive systems were stored, mixed and processed according the recommendations given by the supplier (see also the information of Table 1). A fixed amount of glue was applied on the outer pole surfaces of a core half with the help of a dispenser. Then a second core half was placed on top. The amount of glue was sufficient to cover the total surface of the mating faces. The excess was removed with a suitable solvent. The core halves were fixed by standard mounting accessories, consisting of a spring-clasp combination (SPR-E42 + CLA-E42). This gave a clamping force of about 180 N, which ensured a thin, uniform glue layer. Figure 1 gives a schematic impression of the core assembly during curing.

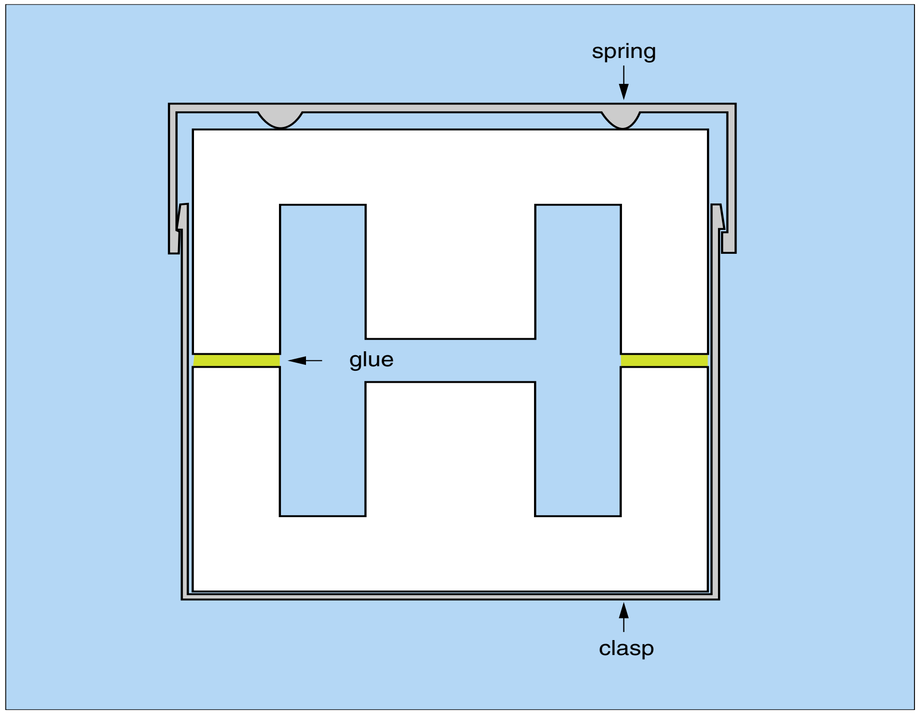


Fig. 1 Arrangement of the mounted cores for the curing of the glue

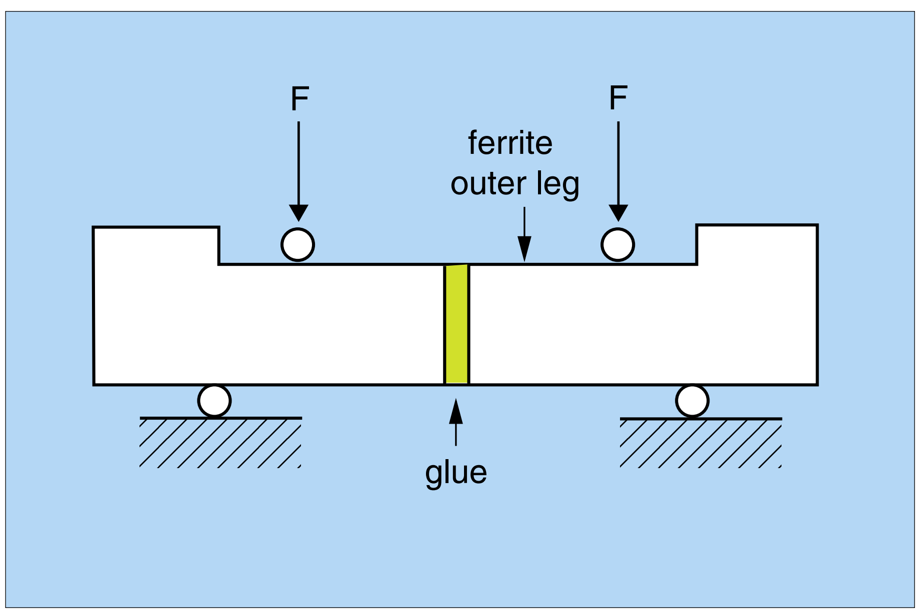


Fig. 2 Test arrangement for the 4-point bending strength test

The adhesives were cured according to the recommended conditions (see Table 1). For all glues, a post-curing for one hour at 80 °C was performed to simulate ongoing curing during normal electrical operation.

The spring-clasp combination was removed after the post-curing step. The two glued outerpoles were then cut into 'bars' to measure the strength of the samples (see Fig.2). The breaking force of the bonded ferrite bar was measured in a 4-point bending test with a loading speed of 1 mm/min. At least 15 samples from each glue type were measured to ensure proper statistical evaluation. Assembled cores of most glue-ferrite combinations were further treated as follows:

1.No ageing
(reference initial strength)

2.Thermal cycling
(-40 °C $\leftrightarrow$ +125 °C)

3.Pressure Cooker test
(+25 °C $\leftrightarrow$ +120 °C at 2 bar)

For more details of the test conditions see Appendix.

The maximum breaking forces were recorded and the fractured surfaces examined using fractography techniques. One can observe the following mechanical strength (S) situations (see also Fig.3):

1. $S_{glue} > S_{ferrite}, S_{glue\text{-}ferrite}$
A major proportion of the bars break in the ferrite material, which means that the intrinsic strength of the glue is greater than that of the ferrite

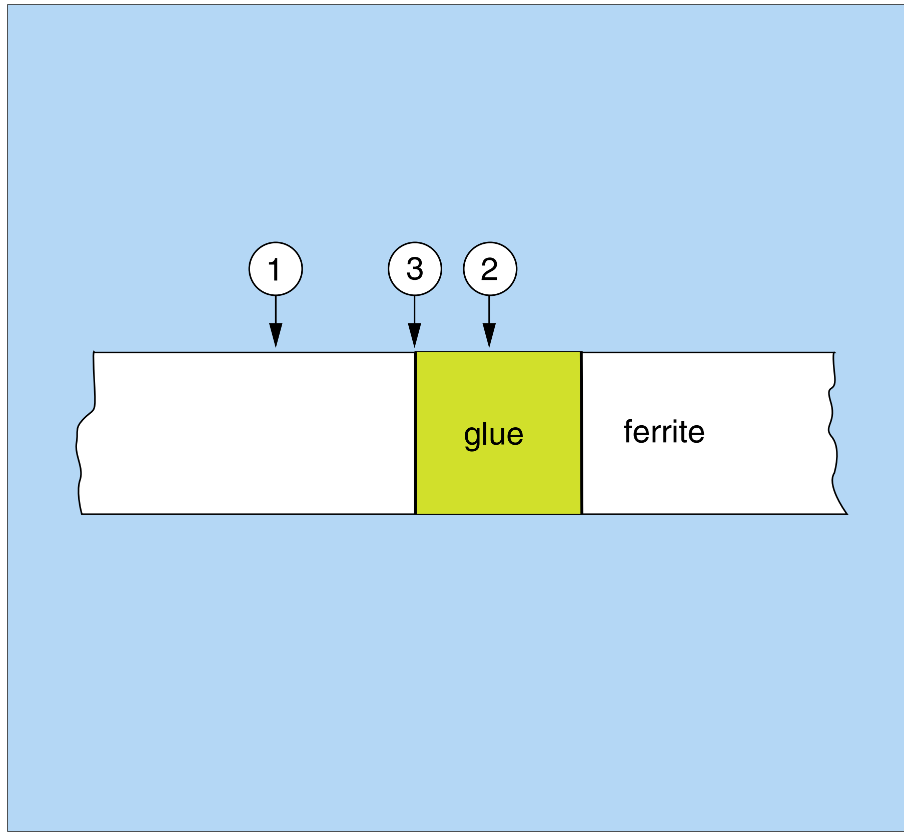


Fig.3 Fracture modes of the glued ferrite bars

2. $S_{glue} < S_{ferrite}$
A major proportion of the bars break in the glue bonding and not in the ferrite. This means that the intrinsic mechanical strength of the glue is less than that of the ferrite material and the adhesion of the glue onto the ferrite surface.

3. Low adhesion of glue to ferrite. Full separation of the glue from the ferrite surface; the adhesion of the glue to the ferrite surface is less than the intrinsic mechanical strength of the ferrite and the glue,

The preferred situation will be (1), especially after the various ageing tests, because the glue will then not be the strength limiting material for a specific application (ref. 6). Even situation (2) is acceptable for most applications. Situation (3) is not desirable although the absolute strength can still be great enough for certain applications.

Table 2 Summary of the mechanical strength measurement results before/after ageing tests.

Sample nr	Fracture 0-hrs	Fracture Nb-test	Fracture PCT
1	(1) ferrite	(1) ferrite	(2) glue
2	(1) ferrite	(1) ferrite	(2) glue
3	(1) ferrite	(1) ferrite	(1) ferrite
4	(1) ferrite	(1) ferrite	(1) ferrite
5	(1) ferrite	(1) ferrite	(2) glue
6	(1) ferrite	(1) ferrite	(2) glue
7	(1) ferrite	(1) ferrite	(2) glue
8	(1) ferrite	(1) ferrite	(2) glue
9	(1) ferrite	(1) ferrite	(2) glue
10	(1) ferrite	(1) ferrite	(3) interface
11	(2) glue	(1) ferrite	(1) ferrite
12	(1) ferrite	(1) ferrite	(3) interface
13	(1) ferrite	(1) ferrite	(3) interface
14	(1) ferrite	(1) ferrite	(2) glue
15	(1) ferrite	(1) ferrite	(2) glue
16	(1) ferrite	(1) ferrite	(2) glue
17	(1) ferrite	(1) ferrite	(1) ferrite
18	(1) ferrite	(1) ferrite	(2) glue
19	(1) ferrite	(1) ferrite	(2) glue
20	(1) ferrite	(1) ferrite	(3) interface
21	(1) ferrite	(1) ferrite	(2) glue
22	(1) ferrite	(1) ferrite	(1) ferrite
23	(1) ferrite	(1) ferrite	(2) glue

Table 3.The effect of temperature and moisture on the expansion of epoxy, acrylic and ferrite materials.

Material type	Thermal expansion coefficient (10^{-6}°C^{-1})	Maximum moisture absorption (wt %)	Volume expansion at maximum moisture (10^{-6})
Epoxy	75	1.8	35
Acrylic	65	0.5	7
Ferrite	10	-	-

Results & discussion

Table 2 summarises the initial mechanical performace of all glues and the results after different ageing tests.

The best adhesives in the test were Eccobond 2332-17, Eccobond 50248-F15, Threebond 2273, 3M DP-490, and Hysol RE2039 +HD0243. With these glues, fracture occurred in the ferrite indicating that they were stronger than the ferrite material itself (classification 1 in the Table)

For all other glues tested, the mechanical strength was found to be less than that of the ferrite.

One glue (Threebond 2273) improved after the thermal annealing test. This phenomenon can be explained by the continued curing at the higher temperature. One could also conclude that the recommended curing conditions were not sufficient for complete conversion into a fully cross-linked polymer system.

The ageing tests at high relative humidity are very severe for the adhesive systems. It is still not clear to what extent ageing tests are appropriate for various applications.

The effect of temperature and moisture on the expansion coefficient of the glue are different for acrylic and epoxy based adhesive systems. Table 3 gives some typical data on epoxy and acrylic materials (Ref.4) and on ferrites. The thermal expansion coefficient of (Mn,Zn)-ferrite has been included for comparison (Ref.5). Since ferrites do not exhibit any open porosity, moisture absorption is negligible. The expansion data shows that the glue-ferrite interface is subject to stresses during the temperature cycling tests. In addition, the combination with moisture can affect the chemical and/or physical bonding of the glue to the ferrite surface (ref. 7).

Conclusions

The best adhesive systems before and after the ageing tests are: Eccobond 2332-17, Eccobond 50248-F15, Threebond 2273, 3M DP-490, and Hysol RE2039 +HD0243. This conclusion does not, however, disqualify the other glues. Other aspects, not taken into account, can also be very important for the final choice, e.g. suitability for an existing assembly process, the number of components, relevance of moisture stability, required curing conditions (short/long time at room/elevated temperature) and cost.

Thermal ageing tests may initiate further curing which leads to higher mechanical strength of the glue. Consequently, the recommended curing conditions do not always result in a complete curing of the adhesive system.

All adhesive systems deteriorate during ageing tests at high relative humidity. Eccobond 2332-17, Eccobond 50248-F15, Threebond 2273, 3M DP-490, and Hysol RE2039 +HD0243, however, were found to maintain their mechanical and adhesive strength during the pressure cooker tests.

Ageing test conditions

All samples were cured according the recommended curing conditions of the adhesive supplier (see Table 1). Additionally, a post-curing of 1 hour at 80 °C was performed. The mounting accessories were removed before the ageing tests. The glued cores were cut into bars after the ageing tests in order to enable them to be tested using the 4-point bending test.

Thermal cycling (Nb-test)

This test is described in IEC norm 68-2-14. Five cycles were performed.

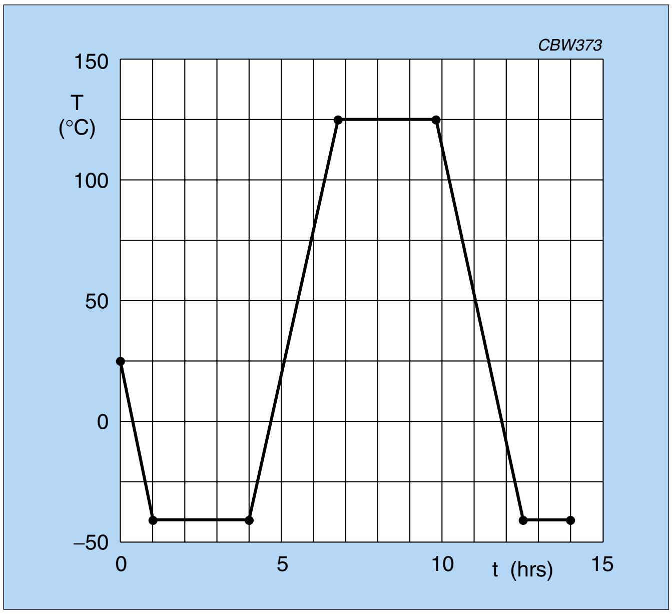


Fig.4 Thermal cycling (Nb) test

Pressure cooker

The test conditions are defined according to an internal Ferroxcube norm. Five cycles were performed.

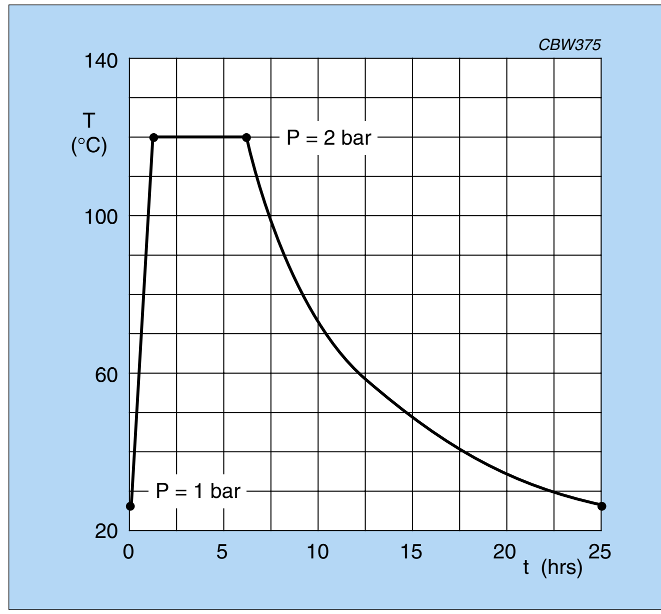


Fig.5 Pressure-cooker test

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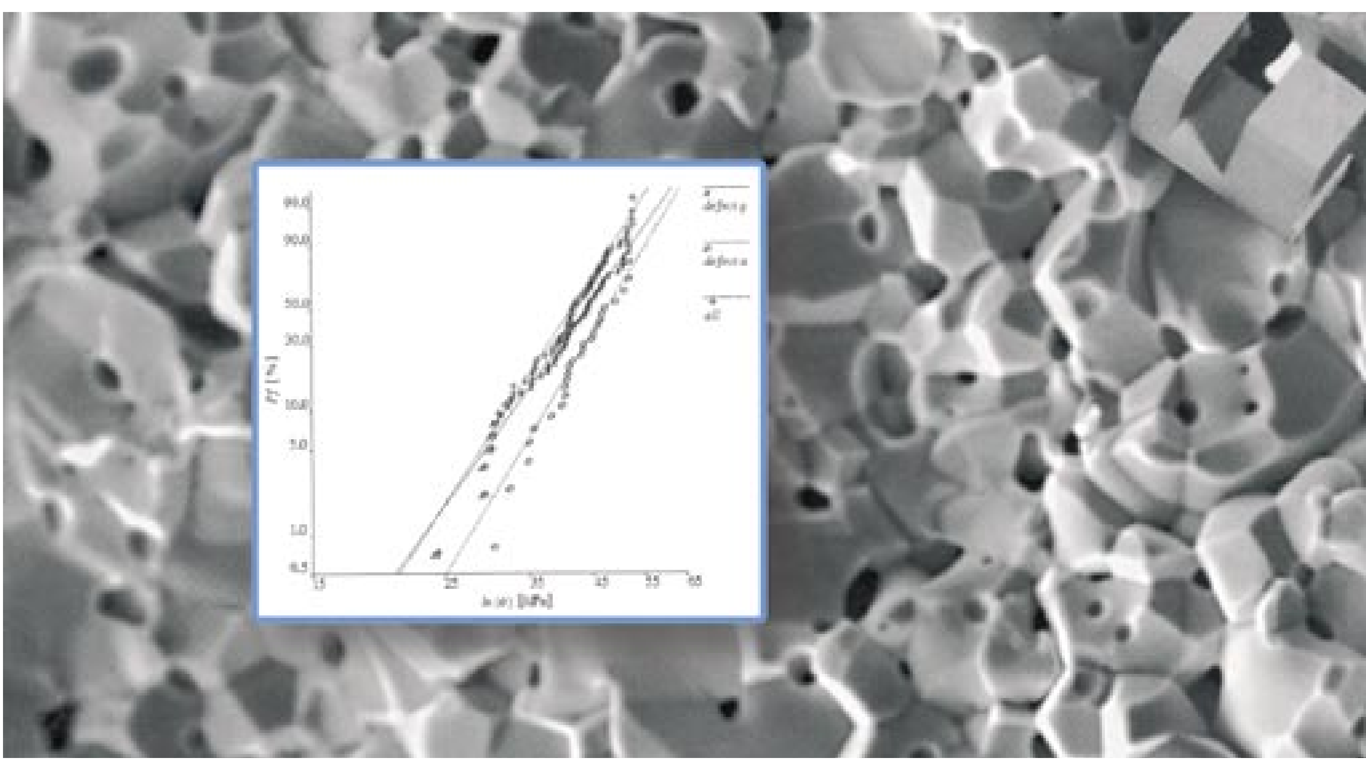
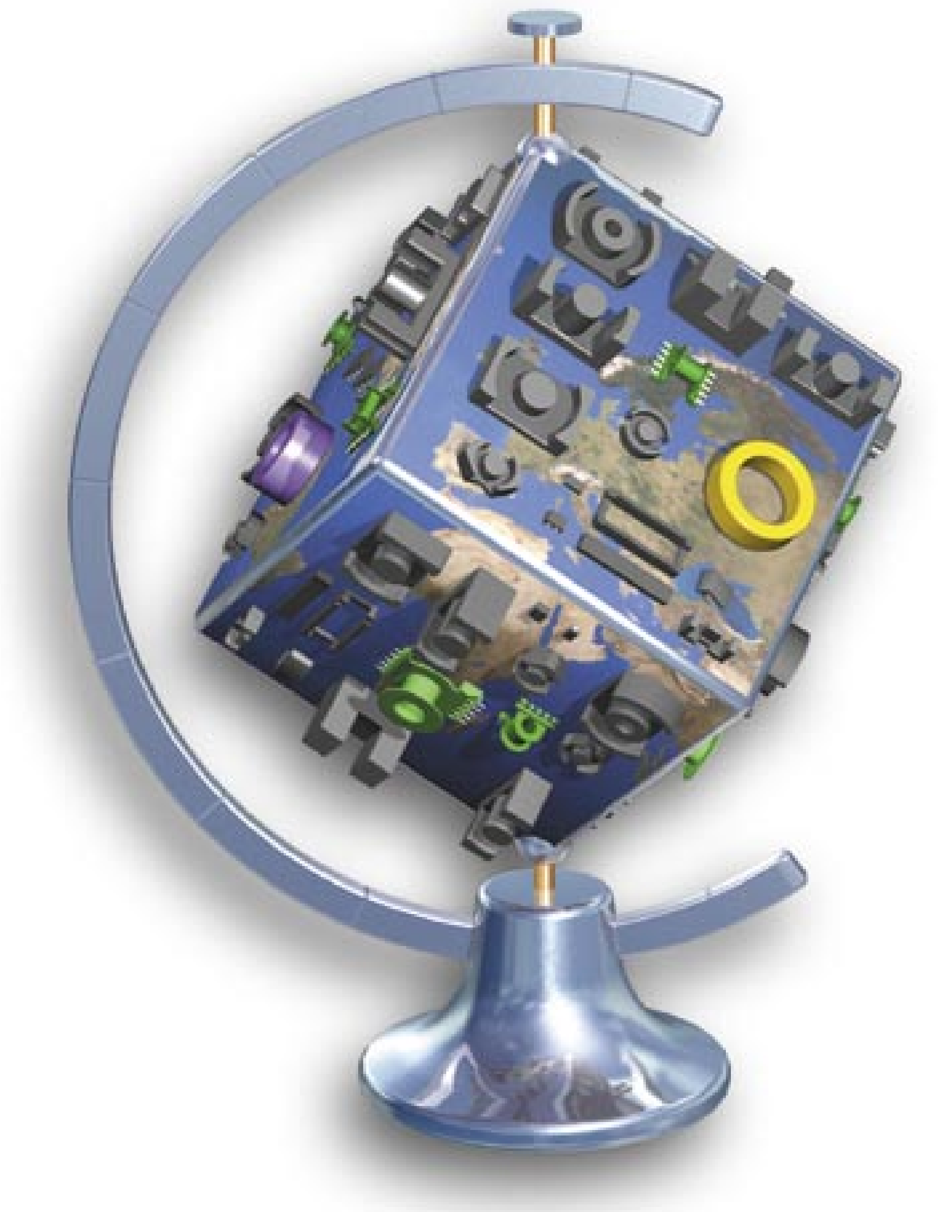


Impression of a cracked ferrite surface



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