

The Drop Test: Deterioration of Magnetic Shielding Due to Mishandling or Abuse

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Magnetic Shields were subjected to controlled shocks in a way that represents the type of accident which occurs in normal use. The results yield information on deterioration of shielding effectiveness, the usefulness of reanneal and material sensitivity to abuse. It is concluded that magnetic shields should always be handled with great care.

Introduction

It is well known that any shock such as vibration, dropping or striking lowers the effectiveness of a magnetic shield, but it is not known just how much, in what way and to what extent it can be restored. At what point will its attenuation factor deteriorate beyond acceptability? For the purposes of this paper, attenuation factor is defined as:

$$\frac{B_{out}}{B_{in}} = \frac{\mu t}{2d}$$

Where B_{out} represents the magnetic field without the shielding cylinder in place

B_{in} represents the magnetic field with the shield in place

μ = permeability of shield

t = thickness of shield

d = diameter of shield

While physicists studying magnetic material have an understanding of the changes which occur when high μ materials are stressed to various degrees, their results are obtained under controlled laboratory conditions and are difficult to apply in the complex conditions of a "real world" shield accident. As a result, in practical cases there have not been complete, useful answers to the questions raised above. There have been intelligent hunches and guesses guided by understanding, but no conclusive results have been available from appropriately planned experiments.

Therefore, we examined the effect of such accidents by shocking magnetic shields in a manner to simulate events in the field. While generalization from any set of experiments is limited, the results presented here do offer answers to the above questions.

Sample Preparation

For simplicity, the parameters of the experiment were limited to a sample involving one material, one thickness and one geometry. The material was an 80-percent nickel-iron alloy which its manufacturer specified to have the following percentage of alloying constituents:

Ni: 80.1, Mo: 4.33, Mn: 0.52, Si: 0.32, C: 0.018, P: 0.002, S: 0.001
The manufacturer's testing of ring samples of this material, according to the induced current (ASTM test #A-753), provided the potential permeability value: $\mu=95,010$ at $B=40$ Gauss.

For statistical reliability in evaluating the results, five identical samples were constructed. The samples were shielding cylinders, and all were 6 cm I.D., 25 cm long and 0.5 mm thick. They were made from sheet material by rolling and spotwelding a 1.2 cm overlap at 9.5 mm intervals along the axis.

After the cylinders were made, attenuation tests were performed according to ASTM specification 698-74 (the Helmholtz method) in a 60 Hz field of 2 Oersted (see Fig. 1). The following values were found for the attenuation factor:

Shield:	1	2	3	4	5	Average
Attenuation:	14	13	14	14	13	13.6 ± 0.55

The mean value of the attenuation factors is 13.6 ± 0.55 , where 0.55 is the statistical standard deviation of the measurements. This means that if the test were repeated with equivalent samples, 68 percent of the measured values should fall in the range of $13.6 - 0.55$ to $13.6 + 0.55$. This notation will be used throughout as the size of the standard deviation as an indication of the reliability of the result. In this case, the standard deviation is only four percent of the mean value indicating an excellent uniformity.

Following these tests, the cylinders were subjected to a full hydrogen anneal in a furnace complete with strip chart recorders and cam controllers. Anhydrous ammonia is cracked at 955°C to make pure dry hydrogen at a dew point of minus 50°C. They were soaked for three hours at 1177°C and cooled at an average rate of 200°C per hour.

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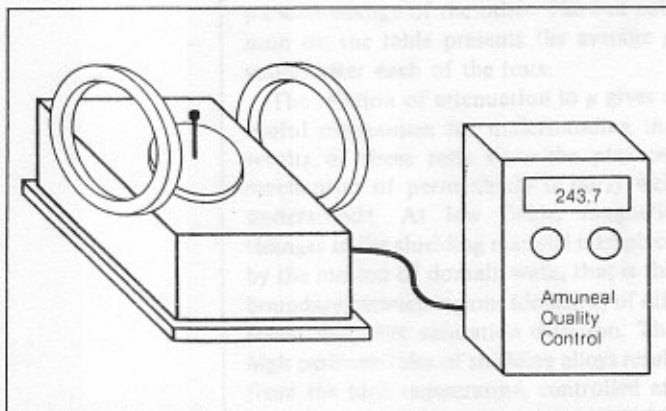


Figure 1—Every Amuneal magnetic shield is tested for attenuation and shielding effectiveness in accordance with ASTM 346-64: "Standard Test Method for Magnetic Shields." This assures that each shield meets the specified requirements of the application for which it is intended. Results of such tests can be supplied on customer request.

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The attenuation tests were repeated, now giving:

Shield:	1	2	3	4	5	Average
Attenuation:	526	500	500	487	500	502.6 ± 14

Note that the high temperature anneal increases magnetic attenuation by a factor of 37.

Drop Tests

To provide realistic shock conditions, each cylinder was oriented with its axis horizontal and dropped from fixed heights to a linoleum-covered wooden floor. No attempt was made to control the angle of impact, bounce or distortion of the cylinder as a result

of the drop.

A specific test schedule was used:

- Phase 1 --Three drops from a height of 30.5 cm. The attenuation was measured after each drop
- The shields were rolled and sized to return the cylinders to their original shape
- They were again annealed in an identical manner to the first anneal
- Their attenuation was remeasured
- Phase 2 --Three drops from a height of 61 cm. The attenuation was measured after each drop
- The shields were rolled and sized to return the cylinders to their original shape
- They were again annealed in an identical manner to the first anneal
- Their attenuation was remeasured

- Phase 3 Eight drops from a height of 93 cm. The attenuation was measured after each drop

Measured attenuations for the entire series of tests are given in the table.

Interpretation of Results

Figure 2 shows the change of the average attenuation through the entire test program. This figure can be understood in terms of changes of the permeability, μ , of the shielding alloy, where μ is the permeability of the shield material. Values of μ can be obtained from the expression for the shielding factor of a long, thin-walled cylinder in a field which is perpendicular to its axis:

$$\text{Attenuation factor} = B_{out}/B_{in} = \mu t/2d$$

where t is the wall thickness and d is the diameter. For the cylinder dimensions used here a value of $\mu = 100,000$ yields an attenuation of 413. Note that the attenuation and permeability are directly proportional so that a change of one corresponds to a parallel change of the other. The last column on the table presents the average μ values after each of the tests.

The relation of attenuation to μ gives a useful mechanism for understanding the results of these tests since the physical mechanism of permeability is fairly well understood†. At low fields, magnetic changes in the shielding material take place by the motion of domain walls, that is the boundary between regions (domains) of different magnetic saturation direction. The high permeabilities of shielding alloys result from the high temperature, controlled atmosphere and annealing process which eliminates impediments to the easy domain wall motion since the easier the wall motion the higher is the permeability. These wall motion interferences are primarily due to impurity atoms (e.g., carbon) and strains

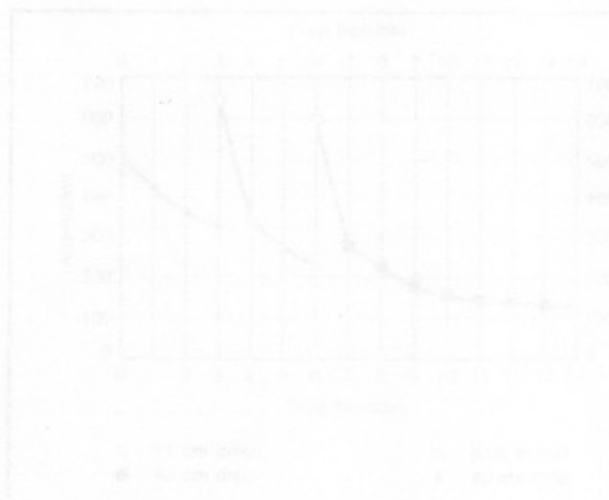


Figure 2--Average magnetic attenuation of the shields after a sequence of drops at increasing and decreasing heights

Table of Attenuation Values and Permeability

Shield:	1	2	3	4	5	Average
First Anneal Attenuation	526	500	500	487	500	502.6 ± 14
30.5 cm drops						
Drop 1	451	441	436	440	478	450
Drop 2	363	375	359	371	403	366
Drop 3	374	361	374	357	403	374
Second Anneal Attenuation	531	505	504	523	525	518
61 cm drops						
Drop 4	298	276	282	277	277	284
Drop 5	250	267	260	274	274	263
Drop 6	274	265	265	252	252	262
Third Anneal Attenuation	314	302	300	305	304	305
93 cm drops						
Drop 7	208	197	217	200	176	200
Drop 8	187	177	181	194	189	187
Drop 9	181	181	142	140	188	168
Drop 10	143	123	127	140	168	140
Drop 11	153	121	126	142	133	135
Drop 12	148	122	117	120	124	126
Drop 13	125	126	157	114	141	133
Drop 14	125	123	121	175	147	140

in the crystal structure ("strain" being used here in the technical sense of atomic misorientations) which tend to "pin" the domain boundaries. The shock of dropping the shield would be expected to induce such strains, pinning the walls and thereby decreasing μ and the attenuation.

Creation of strains as pinning sites is an "energy activated" process, meaning that a specific amount of energy is required to generate each atomic displacement. In such cases it is well known that there is a logarithmic (or, depending upon how one views the results, an exponential) dependence on the energy availability from the source. In our tests, for example, the source property might be the height of the drop or the number of impacts. Since there are mechanisms, such as the softness and distortion of the shield material, which limit the transmission of impact energy to the atomic-crystal structure, some dependencies may not reveal themselves in any study.

However, the form of the graph of Fig. 2 is suggestive since the

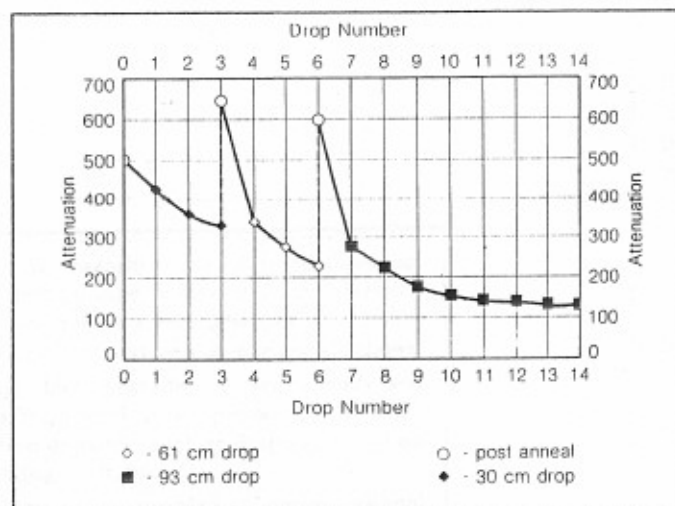


Figure 2—Average measured attenuation of shielding cylinders after a sequential schedule of annealing and controlled shocks from dropping

Table of Attenuation Values and Permeability

Shield:	1	2	3	4	5	Average	$\mu/10^5$
First Anneal							
Attenuation	526	500	500	487	500	502.6 ± 14	1.215
30.5-cm drops							
Drop 1	400	393	400	444	476	422.6 ± 36	1.023
Drop 2	363	370	357	370	350	362.0 ± 8.6	.876
Drop 3	357	303	333	303	338	326.8 ± 23	.791
Second Anneal							
Attenuation	625	625	714	625	625	642.8 ± 40	1.556
61-cm drops							
Drop 4	298	322	333	377	350	336.0 ± 30	.813
Drop 5	250	265	285	277	277	270.8 ± 14	.655
Drop 6	215	215	229	222	232	222.6 ± 7.8	.539
Third Anneal							
Attenuation	544	588	588	625	645	598.0 ± 39	1.447
91.5-cm drops							
Drop 7	259	277	277	270	277	272.0 ± 7.9	.658
Drop 8	227	212	215	202	238	218.8 ± 14	.530
Drop 9	181	181	142	181	166	170.2 ± 17	.412
Drop 10	153	153	133	142	166	149.4 ± 12	.361
Drop 11	142	133	125	142	133	135.0 ± 7.2	.327
Drop 12	142	133	117	133	133	131.6 ± 9.0	.318
Drop 13	133	133	117	133	117	126.6 ± 8.8	.306
Drop 14	133	133	111	125	117	123.8 ± 9.8	.300

shielding deterioration with drop number has the form on an exponential decay. Furthermore, we note that the attenuation factor, for the first drop after each anneal, has nearly the same value it had before the anneal. These relations are made more apparent on Fig. 3, to be discussed below. Note that the scale of μ is not uniform on Fig. 3, since it is the logarithm of μ which is plotted as a function of the drop number. It is clear that a straight line results, indicating that the logarithmic dependence, discussed above, does apply here.

Conclusions

To obtain the straight line on Fig. 3, the points for drops 3 and 4 are plotted together, as are the points for drops 6 and 7. The fact that a single line then spans the entire range means that, after an intermediate anneal, a single drop-shock almost reduces the sample to the condition it had before that anneal. We therefore have an intermediate conclusion that the effect of reannealing the abused

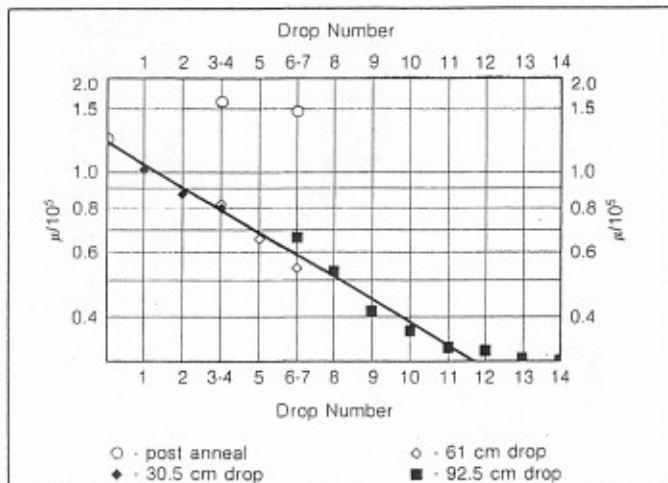


Figure 3—Permeability changes during drop tests, showing a semi-logarithmic variation over a range of 11 to 12 drops

magnetic behavior is relatively insensitive to strains. It follows that if these tests were performed on other commonly used shielding alloys, one would expect to observe greater changes.

The results of these experiments may be summarized as follows:

- I. Dropping a magnetic shield degrades the permeability and lowers the shielding effectiveness. It is expected that this same is true for any vibration or shock, such as dropping a tool on a shield surface, walking on it, etc.
- II. A degraded shield can be re-annealed to restore optimal magnetic properties. If this is done, the subsequent sensitivity to abuse is greater than that of the "virgin" shield but, in any event, the shield performance is never worse than it is without the reanneal.
- III. Full hydrogen anneal is mandatory for maximum shielding attenuation.

REFERENCE

- † For more information see: *Magnetic Materials* by R. S. Tebble and D. J. Craik (Wiley-Interscience, 1969), Ch. 13.

*Sy M. Kamens passed away August 23, 1986.

shields is practically eliminated by a single new shock incident. Note that the shield is still better than if no reanneal had taken place (it is much better if there is no subsequent abuse) but it seems to be the initial anneal, after fabrication, which sets the response rate. It appears that shield abuse might set a "pattern" for strains in the material and, while the strains themselves may be annealed out, they more easily reappear in response to subsequent shocks.

Figure 3 also shows that after a number of impacts (11 drops in this case) there is saturation of the strain mechanism, so that further changes are much smaller. Here we see that the total change of μ , and of the shielding effectiveness, is by a factor of 4 or 5.

The fact that a single line passes through all the points on Fig. 3 also implies that the difference between a 30 cm drop, or a 60 cm drop, or a 90 cm drop is not a major factor in effecting the shield. It is true that the immediate change of permeability is greater for the greater distance drops after each anneal, but this merely serves to return the datum point to the straight line. It is important to realize that this conclusion is based on the scantiest of evidence, and more testing, perhaps over a larger range or with different types of strain-inducing shocks, would be necessary to settle this point.

For no data point is the standard deviation greater than 8.5 percent, and it is generally much lower. Such small values impart great confidence that the test results represent behavior which would be found with other, similar types or tests, and that our conclusions are reliable.

We should note that for the alloy composition used here, the material constants which determine sensitivity to structure are known† to be very small, so that the