FATIGUE DAMAGE BOUNDARY – BACKGROUND, STATUS REPORT, AND CALL FOR HELP

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The "Traditional" Damage Boundary

The Damage Boundary (DB) approach to assessing product shock fragility has been around for over 30 years[1]. Briefly stated, it is a method of determining *what shock pulses will damage a product, and what shock pulses will not*. The traditional Damage Boundary plot (Figure 1), with axes of Peak Acceleration and Velocity Change, shows the areas (and therefore the pulses) of "damage" and "no damage".

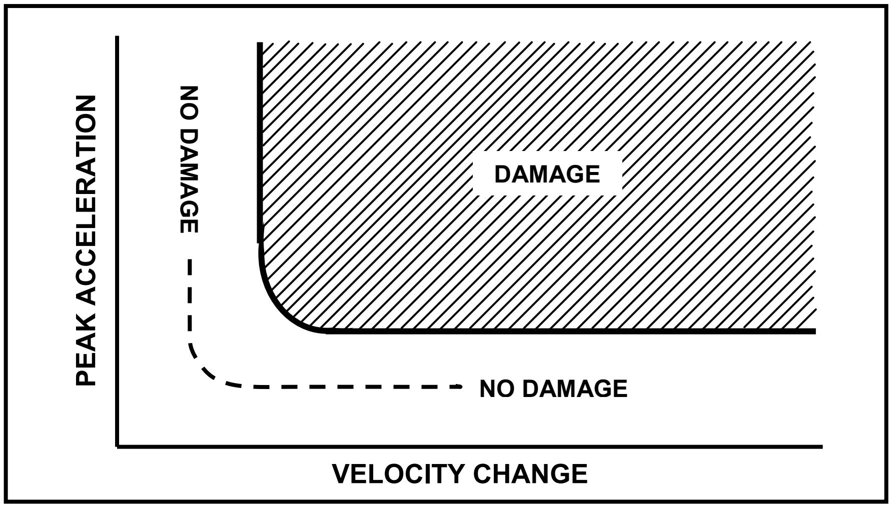

FIG. 1 – Traditional Damage Boundary Plot

DB information is useful in the general sense, but has most often been applied to the design of cushioned packaging. Under shock, the package must transmit less than the "critical acceleration" (g-value of the horizontal line on the DB plot) in order to protect the product. The complete Damage Boundary procedure is detailed in ASTM Test Method D3332[2], the approach appears in MIL-STD-810F Method 516.5, and various versions are included in many other shock testing specifications.

Although Damage Boundary has proven itself to be both practical and useful, over the years some shortcomings have been recognized. Most of these have been addressed, but one that remains relates to the issue of "cumulative damage", which is the subject of this article.

Brittle and Ductile Failures

Many materials like glass, hard plastics, and tempered steel fail in a “brittle” mode; i.e. damage occurs at a specific stress level, with little or no permanent deformation beforehand. Repeated shocks below the failure level cause essentially no degradation, but a single shock application above the critical level results in failure. Prior shock history has basically no effect on the critical level.

In contrast, “ductile” materials such as soft metals and soft plastics fail more gradually; i.e. they become stretched, dented, or deformed before failure occurs. Low-level applied shocks may not initially cause damage, but they degrade the materials. Multiple applications of these low shocks eventually can cause failure. Thus damage is determined by the cumulative effects of both shock level and number of shock applications.

Traditional Damage Boundary methodology assumes brittle failure, and many real products do fail in the “brittle” mode. But many other products fail due to cumulative damage or “fatigue”, and the traditional DB approach does not take this into account.

The Fatigue Damage Boundary (FDB)

Dr. Gary Burgess of Michigan State University’s School of Packaging has been thinking and writing about the effects of fatigue on shock fragility determination since at least 1988[3,4]. He postulates that the “damage” area on the DB plot is related to a third parameter, the number of impacts (N). In other words, failure is defined not only in terms of the vertical and horizontal DB lines (“critical velocity” and “critical acceleration” respectively), but also in terms of N. See Figure 2, which is an example of a “family” of FDB curves for different values of N.

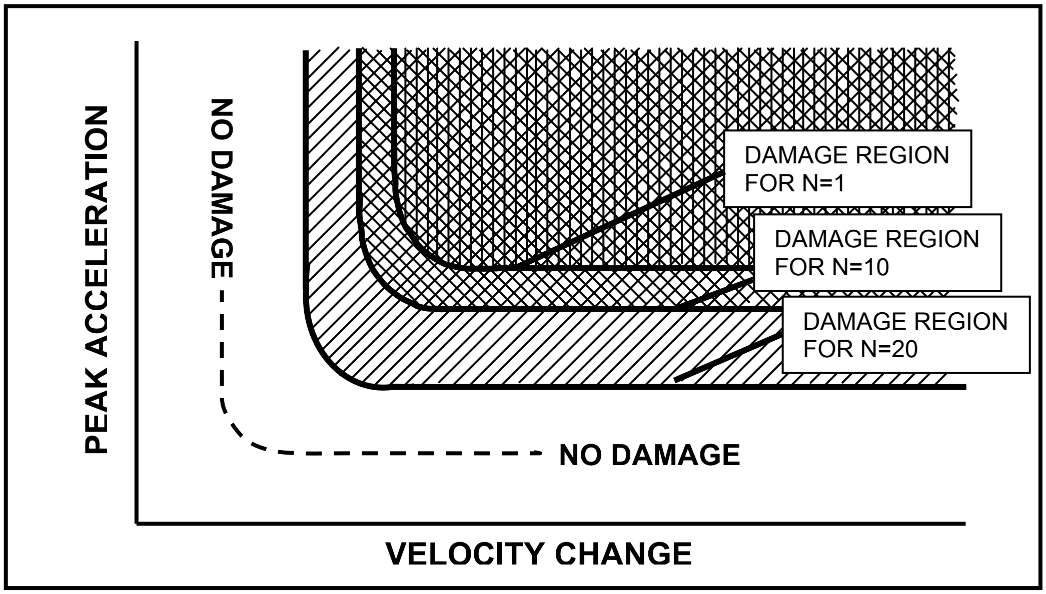

FIG. 2 – Fatigue Damage Boundary (FDB)

FDB represents a *general* procedure, and covers the situation of brittle failure as a *special case*. For example, if a specimen were made of glass, the FDB procedure would find that there is *only* an N=1 damage area; attempts to find damage at lower levels and greater N's would prove fruitless. But for products which fail in a ductile mode, FDB would find the dependence on N, whereas the traditional DB approach would not. The more general FDB procedure produces *complete* data on product fragility, and therefore has the potential of leading to better product and package designs.

Finding the Fatigue Damage Boundaries

The original suggested FDB determination approach was straightforward: set up a low-level shock and repeat until the product fails, recording the input pulse parameters and the number tests to failure. Step up the level and repeat with a new product. Do this several times, and for both the "critical velocity" and "critical acceleration" DB lines. After a number of products and many tests, there will be enough data to plot the family of FDB curves. For example, Figure 2 represents at least 6 damaged products (one for each vertical and each horizontal DB line) and 62 separate shocks. Since each DB applies to only one product axis and direction, a complete Figure 2 procedure could require a total of 372 shock tests and 36 broken products!

Initial results with simple laboratory models and some actual products seemed to corroborate the theory and test method, but in general the industry didn't seem very interested. Burgess and his students continued their FDB development, but for years it remained more or less a "laboratory curiosity".

Part of the problem was a lack of understanding (which was addressed through further work and publications), but the larger issue was the amount of testing and test specimens required. In commercial applications it is often difficult to get even a *few* products to test (and *break*), let alone 30 or more.

In 1999, Matt Daum of Hewlett Packard received his Ph.D from Michigan State University. Building on the work of Burgess and others, his thesis was entitled "Shock Response Spectrum and Fatigue Damage: A New Approach to Product Fragility Testing" [5]. A portion of Daum's work suggested there might be a "shortcut" to FDB determination. Perhaps it is possible, he theorized, to destructively test only *two* products (the same as for the traditional DB approach), determine the natural frequency of the fragile component from a *non-destructive* vibration test, then use this data to *calculate* the complete family of FDB curves. The calculation equations are based on idealized behavior of single-degree-of-freedom (SDOF) spring-mass systems, similar to the foundation of the original Damage Boundary theory.

Where Are We Now?

Initial test results with simple models and this "shortcut" approach looked promising, but tests of actual products were difficult to accomplish, few in number, and the outcomes were largely inconclusive. Industry's attention had been captured, however, and in 2001 ASTM's D10 Committee on Packaging embarked on a program to verify the approach in the real world. To date two products (inkjet printers and light bulbs) have been tested, and the results are being analyzed. But much more data, from a broad range of products, is needed to validate the approach. Dr. Burgess, MSU, ASTM and others will continue working on this project, but the testing of more and different products is sorely needed.

Would You Like to Help?

If you have Damage Boundary shock testing capability and would like to be involved in this important work, please e-mail the author at wikipp@attbi.com. We ask that you provide at least 6 identical products for test; we will furnish a test procedure, backup information, and guidance throughout. Who knows, you may gain valuable information about your product's ruggedness, and in any case will be contributing to a significant potential advancement in testing technology.

References

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