The Truth About Scratch and Dig

David M. Aikens
Savvy Optics Corp, 35 Gilbert Hill Rd., Chester, CT 06412
daikens@savvyoptics.com

Surface imperfection specifications (i.e. Scratch-Dig) are the most misunderstood, misinterpreted, and ambiguous of all optics component specifications. It is time to de-mystify this problematic specification once and for all. This paper outlines the long history of the surface imperfection part of MIL-PRF-13830B, its origins, and intent. A brief comparison of the visibility of various sets of standards and an overview of alternatives available to define a more objective surface imperfection specification are provided.

OCIS codes: 220.4840 Testing, 120.4800 Optical standards and testing

1. Introduction – The scratch standard is only a cosmetic standard [1]

For more than fifty years, the de facto standard method of describing surface quality in optics has been with a pair of numbers referred to as the scratch and dig specification. And for almost as long, people have been trying to use this cosmetic standard to control surface imperfections on precision optics, where scratches and digs affect the performance of the system. The result has been confusion and misunderstanding. The scratch and dig specification is a highly subjective visibility standard, which may be adequate for cosmetics, but insufficiently quantitative for performance-based specifications.

This is not a secret. Matt Young made this clear in a series of articles [1-5] published in the 1980's. But in the 1980's, there wasn't much we could do about it. There was no way to specify scratches and digs that was quantitative, objective, and did not require extensive capitalization. Fortunately, this is no longer the case.

The scratch and dig standard works for military applications, in part because the comparison standards are certified and supplied by the end customer, who has the capital equipment and expertise required to make each set compliant to the standard. But for commercial applications of this standard, the comparison standards need to be clearly articulated in the specification, or the requirement is almost meaningless.

2. An abbreviated history of scratch and dig.

What we currently refer to as the scratch and dig specification is actually Section 3.5 of MIL-PRF-13830B. It, in turn is based on MIL-O-13830, first released as a military standard in 1954. The surface quality test is based on a visual comparison, under specific darkfield lighting conditions, of a subject surface imperfection and a comparison standard set to determine the visibility or "grade" of the imperfection. The specification references a drawing for surface quality standards, C7641866. This approach to surface imperfections was first proposed by McLeod and Sherwood in 1945 [6]. They offered up comparison standards numbered from 10 to 120, to be used in this comparison method. As early as 1945 they recorded that "there is little correlation between the appearance or visibility of a scratch and its measured width." Frankford Arsenal documents dating to the same period declare that "these numbers are arbitrary, and are not to be assumed as denoting the width of the scratch." Scratch morphology is a better predictor of scratch visibility or brightness, than width [7].

At Picatinny Arsenal in New Jersey there is a set of limit standards that date back to 1954, or even earlier. These limit standards are set in pairs, indicating the highest visibility and lowest visibility allowed for a given scratch number. These scratches are the master set from Frankford Arsenal, and are still being used to certify sub-master comparison standard sets which are sent to the field to be used in inspections. The master scratch set has remained intact and virtually unchanged in 50 years [8].

In the 1970's, though, a series of enigmatic revisions were made, not to the MIL specification, but to the drawing C7641866, which have created an enormous amount of confusion in our industry. In 1974, revision H of the drawing specified a comparison set wherein the scratch number was to be the width of the scratch in microns. To make matters worse, in 1976 revision J described a comparison set wherein the scratch number was the width of the scratch in tenths of microns. In all this time, the limit masters and the meaning of, say, a #60 scratch, remained unchanged. Finally in 1980, revision L made all such width notes for reference only. As a result of these unfortunate revisions, there have been many myths and legends in our industry regarding the scratch standard. But the simple truth about the scratch standard is that:

1) The scratch-dig standard is, and has always been, a visibility standard, not a width standard.
2) The scratch number is not the width in microns or tenths of microns.
3) The Army never tightened the scratch specification by 10x.
4) Scratch standards do not "heal" over time. (They do, however, get dirty and need to be cleaned.)

So if the scratch standard is a viable cosmetic standard, why all the fuss? Three things. First, the fidelity of the test depends upon both parties using the same or similar comparison artifacts. Second, the test is subjective; different inspectors will inevitably interpret "visibility" differently. And third, there are applications which really do require a quantitative, width-based specification.

3. The problem with visibility- comparison artifacts

The first problem is that the limit standards are retained at Picatinny Arsenal for government use only. Several companies offer comparison standard sets. Discounting the ones claiming to offer width-based standards and chrome on glass reticles, there are three commercial manufacturers; FLIR/Brysen, Davidson Optronics, and Jenoptik. This last is the plastic paddle sold by both Edmund Optics and Thor Labs. I'm not sure how repeatable any of these standards are, but I suspect each company does a decent job of certifying them to whatever internal masters they have. But they certainly look different. Figure 1 shows a comparison of four such scratch sets, measured under identical dark-field conditions.

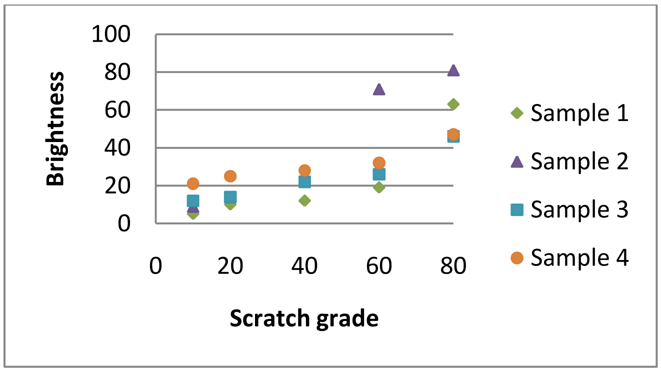

Figure 1. Relative brightness of four comparison sets. Sample 1 is FLIR/Brysen S&D 1109, Sample 2 is Davidson Optronics D-667A S/N 2431, Sample 3 is an Eastman Kodak Paddle, EKCO CM2, and Sample 4 is a Jenoptik paddle EO #53-157 CM1.

Clearly, these sets are not mutually compatible. The #10 artifact in Sample 4 is brighter than the #60 artifact of Sample 1. And the #60 artifact of Sample 2 is more than twice as bright as any of the other #60's considered. So the meaning of the visibility of a scratch is dependent on the comparison samples being used. For all commercial procurements, the brand of the comparison standard should be referenced on the drawing. For example, "80-50 per MIL-PRF-13830B using brand x comparison standard," is a reasonably unambiguous approach.

4. The problem with visibility- subjective versus objective.

As more companies become ISO 9000 and AS 9100 certified, there is increased pressure to replace subjective inspections with objective tests which can be documented. In the case of scratch-dig inspection, that means finding a way to replace the inspector's judgment with some kind of measurement tool. Such a system, using a digital camera and a fixed dark-field lighting setup, is shown in Figure 2. A screen shot of the software showing the relative brightness of an artifact compared to the measured brightness of a comparison master is shown in Figure 3. For more information about this instrument, contact the author or visit the Savvy Optics Corp website, www.savvyoptics.com.

Figure 2. The SavvyInspector^{TM} SIF-4, an objective, highly repeatable, scratch and dig inspection station.

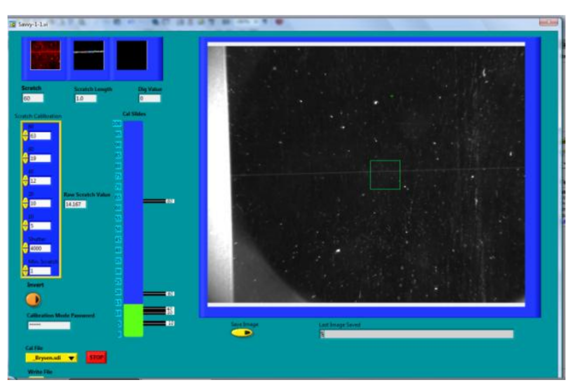

Figure 3. Screen shot showing calibration data and relative scratch brightness using the SavvyInspector^{TM}.

5. The problem with visibility- applications requiring width.

Some applications require a width specification, or are sensitive to scratches too small to see. In 1985, there were no practical alternatives to scratch and dig. Lots of people have tried to extend the usefulness of the scratch-dig standard by adding higher brightness light sources and magnification, which has caused more confusion. In 1996, with the publication of ISO 10110, there was an alternative. Based on the German DIN 3140 standard, part 7 describes all surface imperfections in terms of a "root area", and not only allows but practically requires direct measurement of every scratch and dig. Lately this approach has been gaining momentum, but aside from a few stalwarts, it has not become common practice in the US.

The new revision of the American National Standard for surface imperfections, OP1.002 [8], retains the visibility method from MIL-PRF-13830B, but adds the dimensional method from MIL-C-48497A, which is familiar, easy to use, and effective for people who really require a functional specification. To invoke the visibility specification, the scratch and dig numbers are indicated as before. To invoke the dimensional method, a pair of letters is used, such as A-A or E-E, to reference a specific size of imperfections.

Table 1. Translating incorrect scratch-dig specifications based on scratch width to correct specifications per OP1.002

"scratch width in microns" based indication	Dimensional callout per ANSI/OEOSC OP1.002-2009
10-5	B-A
20-10	C-B
40-20	D-C
60-40	E-E
80-50	F-F

6. The call to action.

This is our industry. And like it or not, the scratch and dig visibility specification is part of it. It is a viable cosmetic standard for optics, but not an objective or performance standard. The mis-interpretation of the scratch number as a width specification is a blight on our industry that costs millions of dollars a year and must be put to an end. Today, alternatives exist that allow us to specify a meaningful surface quality level for our applications, either with an objective control of cosmetic imperfections or for dimensional control of scratches and digs. The time has come to revise our drawings and our training materials and our specifications and our exception sheets and our shop floor guidelines to remove all reference to scratch widths. This is our specification. Let's put an end to this madness, and start telling the truth about scratch and dig.

If you want to learn the story of scratch and dig in all its glory, take my OEOSC accredited course *"Understanding Scratch and Dig."* I teach it periodically at conferences, as well as offering on-site training.

7. References and notes.

[1] M. Young, "The scratch standard is only a cosmetic standard," Proc. SPIE Vol 1164, pp185-190 (1989).

[2] R. E. Fischer, "An interview with Matt Young on the scratch and dig standard for optics," OE Reports, Vol 44 (1987).

[3] M. Young, "The scratch standard is only a cosmetic standard," Laser Focus/Electro-optics Magazine, Annual Optics Review, pp 138-140 (1985).

[4] M. Young and E. G. Johnson, "Redefining the scratch standards," NBS Technical Note 1080, USGPO (1985).

[5] M. Young, "Can you describe optical surface quality with one or two numbers?" Proc SPIE 406, pp 12-22 (1983).

[6] J.H. McLeod and W.T. Sherwood, "A proposed method of specifying appearance defects on optical parts," J. Opt. Soc. Am. Vol 35, pp 136-138 (1945).

[7] G. White and J. Marchiando, "Scattering from a V-shaped groove in the resonance domain", Appl. Opt. Vol 22, No 15, pp 2308-2312 (1983).

[8] This may not be exactly true. At least two of the limit standards are believed to have been damaged and replaced in that period. But their replacements were matched to the originals by Frankford Arsenal personnel.

[8] ANSI/OEOSC OP1.002-2009, "American National Standard For Optics and Electro-Optical Instruments-Optical Elements and Assemblies-Appearance Imperfections." American National Standards Institute, Inc. (2009).