# TECHNICAL REPORT

## ISO/TR 21958

# Ophthalmic optics — Review of the test methods used to assess scratch and abrasion resistance of spectacle lenses

*Optique ophtalmique — Revue des méthodes de test utilisées pour évaluer la résistance à la rayure et à l'abrasion des verres ophtalmiques*

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# Foreword

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This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 7, *Ophthalmic optics and instruments*.

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# Ophthalmic optics — Review of the test methods used to assess scratch and abrasion resistance of spectacle lenses

## 1 Scope

This document describes the most commonly used test methods considered in standardization work relating to scratch and abrasion resistance of plastic spectacle lenses along with their technical capacities and limitations. It includes the ISO test method for assessment of claims for basic abrasion resistance in ISO 8980-5.

This document is intended to be of benefit to any future interest in ISO standardization on scratch and abrasion resistance of spectacle lenses.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

## 4 Background

As the spectacle lens market shifted from glass toward plastic in the 1970s, the demand for improved abrasion resistant coatings for plastic lenses resulted in the need to assess and compare the performance of the new coatings in the market.

A number of very different abrasion test methods were developed over the years which employ a variety of ways to abrade the lens. Each method uses a unique scratch or abrasion mechanism which affects how the lens is assessed for its ability to resist damage.

In addition, different methods of assessment of test lens surface damage are used by these test methods.

Together, the different mechanisms of abrading and the different assessment methods often result in dramatically different ranking and rating of the performances of lens surfaces that do not reflect marketplace performance and the experience of wearers in real life conditions.

Considerable national and ISO standardization activity was directed to find one single test method that would reliably predict wearer experience or market performance. After much work, it was realized this goal could not be achieved and that work was abandoned.

In its place an ISO standard (ISO 8980-5) was successfully developed with a methodology capable of determining whether a lens surface claimed to be abrasion resistant could achieve a basic performance level. This test method follows the only known approach avoiding the possibility of using the standard test to rank products in the market.

Further work followed the successful publishing of ISO 8980-5, this time with the aim of creating a standard for "enhanced abrasion resistance" at a higher level than "basic level".

However, after some years of work, the project group responsible was unable to achieve the objective of a single test able to predict market performance and real wear experience, so further work was abandoned.

This document describes in detail the most common abrasion test methods used for assessing spectacle lens surfaces developed over several decades and which were considered during standardization work, along with their technical capabilities and limitations. It includes the ISO test method for assessment of claims of basic abrasion resistance in ISO 8980-5.

This document also explains the different mechanisms of abrasion and scratching.

# 5 Mechanisms of mechanical abrasion and scratching of lens surfaces

## 5.1 Discussion and scratch mechanisms

When attempting to classify and quantify damage to a lens surface, the spectacle industry itself has differences in opinions on the definitions, descriptions and classifications of damage types. A standardized method for assessing and quantifying such damage is therefore an extremely complex activity that will always have different views on interpretation of test results.

Two typical terms used in the spectacle lens industry to describe lens surface damage are 'abrasion' and 'scratching'.

No single agreed definitions exist for these terms in the industry, however basic descriptions could be:

— SCRATCHING – A process of degrading from a pristine surface of a lens caused by initial contact / impact of an object on a lens surface and then friction / motion of the object across the lens surface.

   synonyms: score, abrade, scrape, roughen, scuff (up), lacerate, groove, gash, engrave, incise, gouge

— ABRASION – A process of degrading from a pristine surface of a lens caused by the pitting or wearing away of the surface.

   synonyms: wearing away/down, wearing, erosion, scraping, corrosion, being eaten away, chafing, rubbing, stripping, flaying, excoriation

An example of *abrasion* might be when one continually rubs a lens surface with a cloth or tissue, and with time a degradation of the surface /coating occurs that alters its appearance and function. *Scratching* might occur if sand or debris were on the cloth and the drag of this particle caused specific localized damage as it was dragged across the surface. The latter is likely to be noticed more readily by the wearer when holding up the lens up to the light as it is less uniform in nature.

One view is that 'Abrasion' is an umbrella term for description of many types of damage to a lens surface and that 'scratching' is just one of the subsets of damage types.

Another view is that Abrasion is typically the umbrella term to describe 'impact' related damage and Scratching is typically the umbrella term used for describing friction related damage.

Scratching is the term often used to describe visible damage to a lens surface that occurs in straight lines.

Scratching is often considered to be a single occurrence of damage with a single contact point from an object and with sustained contact, motion in a continuous direction.

Abrasion is often considered to be the damage caused by repeat occurrences of multiple contact points of an object over a larger surface area.

Both scratching and abrasion mechanisms of damage are dependent on the interaction of factors such as force/pressure, contact area, relative material hardness, duration of contact and repeated exposure to the damage, friction coefficients of the surfaces, surface roughness etc. on the lens. (The 'lens' includes the coating and substrate combination).

Abrasion resistance and scratch resistance are terms that have been typically used in an interchangeable way in the industry. The relevant ISO 8980-5 standard is titled 'Minimum requirements for spectacle lens surfaces claimed to be abrasion-resistant' and uses the term 'abrasion resistance' whereas marketing sectors of the industry usually use the term scratch resistance.

Damage types can be grouped as shown in the Table 1 below.

**Table 1 — Damage types**

| friction related | impact related |
|---|---|
| tearing | pitting |
| cutting | chipping |
| scuffing | clash |
|  |  |

Damage to a lens surface can be a single type or a combination of the types shown in the table above. It can be linear in direction or randomized dependent on the testing mechanism.

'Scratching' may be considered as a combination of both Impact and Friction damage types as a scratch can originate from an object's contact / impact with the surface, and then translate to a friction related mechanism of damage (tearing or cutting), as the object maintains contact and is moved across the surface.

In real life performance, a lens claimed to have significant scratch resistance properties, might actually tolerate one type of damage mechanism well, but perform poorly against a different damage mechanism.

Case study example:

Abrasion damage can be caused by daily wiping off dust and fingerprints from the lenses. The force of our fingertips is roughly 10 N on an area of about 1 cm$^2$. Several wipes with a clean soft cloth do not cause any damage to a clean lens surface. Only after several 1000 wipes the contact angle of hydrophobic topcoats starts to decrease, but usually the coated surface of a lens does not show any visible damage or a change of reflection colour. In real life neither the cloth nor the lens surface always is perfectly clean: there are small grains of any kind of dust or even sand. When wiping over the lens surface they cause the well-known multitude of lighter and stronger scratches, which can be detected on lenses worn for several months. This can be understood by estimating the pressure of a sand grain onto the lens surface. On the cloth side of the grain the soft cloth adapts to the shape of the grain. On the lens side the sand grain and the lens surface can elastically adapt their shapes only a little bit which means that the contact area is much smaller than the diameter of the grain. Assuming that the grain has a diameter of 0,1 mm = 100 μm the contact area roughly is smaller than about (10 μm)$^2$. Because the force is the same as at the cloth side the pressure to the contact area on the lens is 2 magnitudes higher which causes plastic deformation i.e. scratches. Using a microscope typical scratches have a width of 1 μm to 10 μm and a depth of up to 1 μm often accompanied by coating cracks and even delamination.

In addition to cleaning of the lenses there are further typical causes for damaging lens surfaces:

— Storage behaviour, i.e. face down on a car dashboard where there is a level of constant vibration;

— Being placed face down on a hard bench / desk surface;

— Being carried around in a handbag, contacting other articles;

— Being placed in a shirt pocket, constantly rubbing against the pocket material;

— Falling off into the dirt or floor, etc.

## 5.2   Testing and the different forms of damage

There is a range of current tests for assessing product 'resilience' to damage by scratching and/or abrasion mechanisms but, however, no single test has been shown to align with real life experience and the tests typically will create and measure a specific form of damage and interaction between surfaces.

Some input test parameters to the tests as mentioned earlier are: force/pressure, contact area, relative material hardness, duration of contact and repeated exposure to the damage, abrasive media, load, velocity and number of cycles and any combination of these can result in different results of the test, as different mechanism of surface damage occur.

Due to the different mechanical actions employed in the various tests, different directional damage components / forces are involved. Some have consistently linear motions giving linear damage patterns and others have more randomized directions of damage, as shown in Figure 1 below.

Micro-hardness, elastic modulus, roughness and friction play a different role in each type of wear test with its intrinsic predominant dynamic phenomena. Static hardness tests for example do not take into account these dynamic phenomena.

Historically steel wool and taber tests results have shown a dependency on micro hardness and elasticity, while the tumble test shows a dependency on surface roughness. Surface friction however, correlates well to all three abrasion tests.



a) Bayer abrasion haze pattern
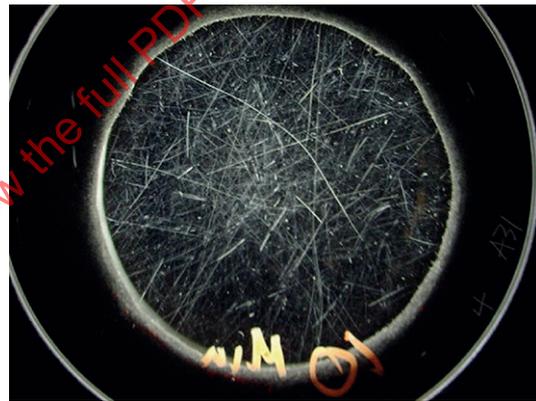
b) Tumble test abrasion pattern

c) Steel wool test

d) Eraser test

Figure 1 — Damage examples

Figure 1 a) shows many fine scratches and a hazy underlying background. Semi-randomized direction to damage pattern – some linear component.

Figure 1 b) shows coarse heavy scratches but a clearer underlying background. Randomized directional damage.

Figure 1 c) shows linear damage pattern from steel wool test.

Figure 1 d) shows linear damage pattern.

## 5.3 Assessing surface damage

The most common methods to assess damage are by measuring changes in luminous transmittance, light scatter, and subjective evaluation of cosmetic appearance before and after damage has been applied.

One problem with this approach is that results can appear to conflict with other methods of assessment. For example, a single heavy scratch that is unacceptable cosmetically might give a satisfactory result in a test based on a scattered light measurement methodology.

Abrasion tests that provide uniform damage (such as the Bayer test) are well suited for assessment using scattered light (haze) measurement techniques. A test like the Tumble test might show more realistic scratch patterns, but is not as well suited to assessment with haze techniques.

A slightly pitted surface might be acceptable in cosmetic terms but give a poor result when tested using a scattered light measurement. Therefore, each test has to be combined with the best fitting kind of damage measurement to get a useful evaluation. Well-proven combinations are for example Bayer test with haze measurement and eraser test with visual examination against a light-dark-boundary as defined in ISO 8980-5.

It may be necessary to get a better detailed understanding of abrasion / scratch resistance of coated lenses. Usually the surface is examined with the aid of microscopes, electron microscopes or even more expensive surface analysis tools.

## 6 Test method description

### 6.1 Steel wool test

#### 6.1.1 Principle

The focus of the test is on the amount of force required to reach the threshold of penetration of the surface before scratching occurs. This test was created specifically to test abrasion resistance coating for the spectacle lens market. It's a friction related type of damage: scratches with linear pattern. Other versions of this test are performed with different grades of steel wool and with different number of cycles and weight and velocity.

#### 6.1.2 Description

#### 6.1.2.1 Surface damage procedure summary

The procedure, for evaluating the abrasion resistance, requires a controlled movement with a specified number of cycles under specified load conditions of a specified steel wool pad, as abrasive medium, over the surface of plastic lenses (see Figure 2).
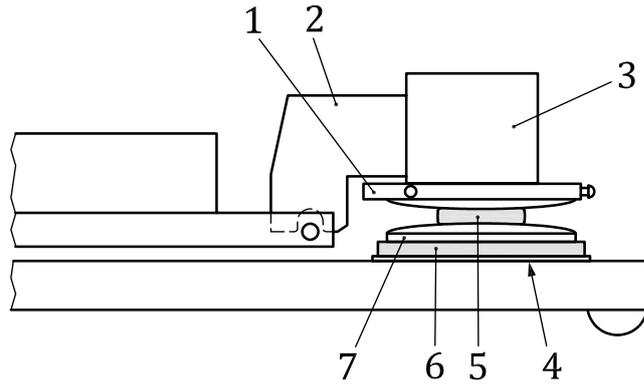
**Key**

1    pad holder
2    block holder
3    1,8 ± 0,2 kg weight
4    metal plate
5    steel wool pad
6    rubber pad
7    test lens

**Figure 2 — Steel wool test diagram**

Each steel wool pad, as shown in Figure 3, is qualified following a detailed procedure and it is fundamental to this test that control lenses of consistent manufacture are used.

One test run consists of a total of 9 lenses (6 samples plus 3 control lenses) abraded using a single steel wool pad properly conditioned.
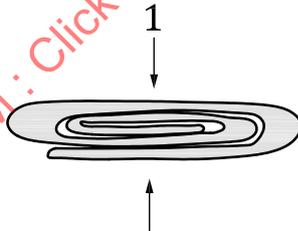


**Key**

1    press flat

**Figure 3 — Folded steel wool**

### 6.1.2.2    Method of assessment of surface damage

The parameter of interest is the average measured increase in damage (as estimated by increase in haze detected by a suitable instrument) after 75 cycles.

Superior statistics can be achieved and confidence in the results enhanced if more data points are available, on which a linear least squares regression can be performed.

Differences can be observed visually when they are significant but the evaluation method for the steel wool test uses haze measurements before and after each sequence (Hazemeter).

The abrasion ratios of test lenses are calculated relative to all control lenses.
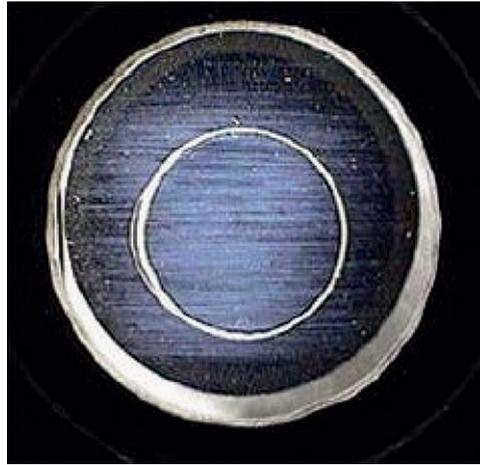
Figure 4 shows an example of steel wool damage.

**Figure 4 — Image of steel wool damage pattern**

### 6.1.3 Pros and cons

#### 6.1.3.1 Pros

— If the most prevalent mode of failure is scratching, the use of steel wool is well suited to quickly generate scratches on the surface of a material in linear motion.

— Evaluate different optically clear materials; same coating (same film thickness) on different substrates.

#### 6.1.3.2 Cons

— There is no worldwide standard for grading steel wool.

— The preparation of the steel wool pad by folding and with proper fibre orientation is critical for measurement. Conditioning of the pads is necessary for improved consistency.

— Haze assessment is not the most suitable method for a linear pattern of damage.

— Different abrasive media load, velocity and number of cycles can result in different results of the test, as different mechanism of surface damage occurs.

— This test method has not been shown to correlate with real-life abrasion resistance of lens surfaces.

## 6.2 Tumble test

### 6.2.1 Principle

The "Tumble test" was developed at a time when tintable hard coatings on plastic lenses were first being introduced into the marketplace. At the time, there was a significant variability in real life performance of coatings claiming to be abrasion resistant. During the tumble test, the lens is placed inside a drum that is rotated. A mixture of abrasive media (scrub pads, foam, wheat, sawdust, silica sand, and emery) is free to move inside the barrel, invoking wear on the lens during the test. The amount of damage to the test lens is compared to the amount of damage on a reference lens that was inside the drum at the same time.

### 6.2.2 Description

#### 6.2.2.1 Surface damage procedure summary

The Tumble test was (and is) rather unique in that the abrasion pattern which results from the test is _not_ uniform. It was designed to more closely simulate what a lens surface generally looks like after a given amount of time when worn in the field. Since wearers unintentionally expose a lens to a variety of different abrasion sources (shirtsleeve, desktop, beach sand, etc.), it is a natural extension to realize that a test that simulates real life patterns might correlate more actual wear.

For each test, an uncoated ADC lens was included in the batch under test. Generally the patterns were different enough between the control and test lens to leave little doubt which surface was worse than the other. For good coatings, the obvious improvement from the uncoated sample was clear evidence that the coating was superior to uncoated.

A tumble barrel with a specified rotation speed was used and lenses placed in the barrel. The following abrasive media became the specified mix for this test[1]: 3M Scrub Pads, White Polyurethane Foam, Whole Bran Wheat, Cube Sawdust, Grit-O-Cob, White Silica sand and number 303 Emery. Other versions of this test are performed with other abrasive mixtures like felt, emery paper and quartz sand.

#### 6.2.2.2 Method of assessment of surface damage

The original method of assessment of the lens abrasion damage did not utilize a specific measurement device to quantify abrasion. Since it was realized that the random nature of the abrasion pattern imparted by the test did not suit itself to traditional measurement methods (haze), a different approach was utilized. Visual ranking of dark field illuminated photographs became the method of assessment.

The dark field photographs shown in Figure 5 are of two samples with differing degrees of tumble test abrasion damage. While this example is for the same lens after 5 min and 20 min abrasion, it could as readily be the results of two differing coatings/materials. If this were the end result of the test after 20 min of abrasion, this would clearly show that at least in this test, the sample on the left was better performing than that on the right.
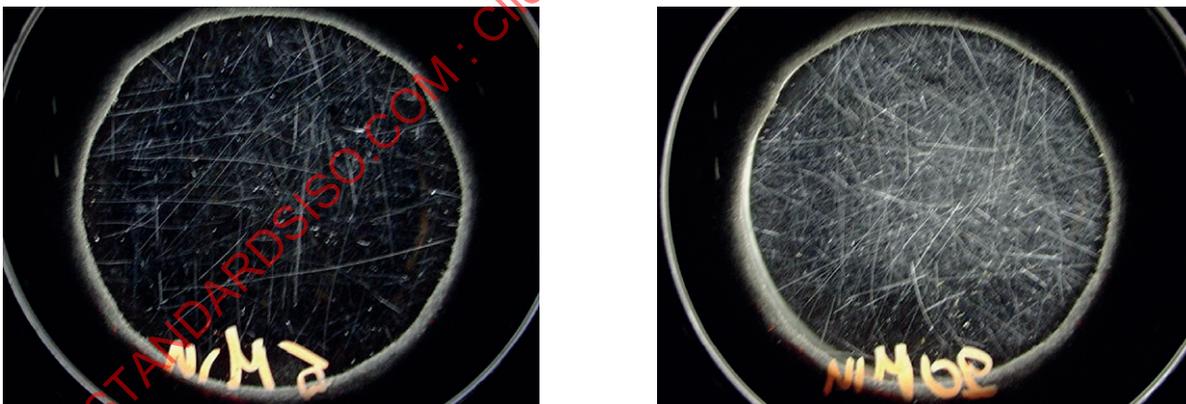


**Figure 5 — Images of tumble test damage pattern**

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1) 3M Scrub Pads, White Polyurethane Foam, Whole Bran Wheat, Cube Sawdust, Grit-O-Cob, White Silica sand and number 303 Emery are examples of a suitable product available commercially. This information is given for convenience of the users of this TR and does not constitute an endorsement of this product by ISO.

### 6.2.3 Pros and cons

#### 6.2.3.1 Pros

— The Tumble abrasion pattern most closely resembles what is seen in real life wear when compared with any other accelerated abrasion test known to exist.

— Visual ranking can be beneficial, as seeing that the pattern is not uniform is instructive. Haze readings used in other tests seldom convey there might be some variability centre to edge.

#### 6.2.3.2 Cons

— The ranking of product surface damage by visual assessment of photographic records from the test was the basis for the original test. Since the dark field illumination photography and subsequent visual analysis did not give a direct means to easily numerically rank product, this test was not universally adopted. There were attempts by some who used this test to modify it to include haze measurements on such samples, but this was met with limited success.

— While this is one of the few tests where published data demonstrated a correlation to real life wear for a specific coating, there have been reported instances where results did not match real life wearer studies.

— Some ingredients in the mixture degrade over time and also might vary in consistency based upon sourcing and vendors used. For any accelerated abrasion test, one of the biggest issues tends to be the consistency and reliability of the media used.

— This test method has not been shown to correlate with real-life abrasion resistance of lens surfaces.

### 6.3 Eraser test

#### 6.3.1 Principle

This test is mentioned in military standard MIL-E-12397A dated 1953 and MIL-C-675A dated 1964 until ISO 9211-4:2012 (Optics and photonics - Optical coatings - Part 4: Specific test methods). It has been used to check the abrasion resistance of optical thin film coatings on mineral substrates. While optical thin film coated mineral spectacle lenses usually do not show any damage by an eraser plastic spectacle lenses are more susceptible to abrasion.

This testing procedure generates different amount of damage to the lens surface depending on the abrasion resistance of the substrate and the coating and the chosen degree of severity of the testing procedure: It ranges from no damage at all, single short light scratches, or a multitude of light or stronger scratches until a stripe of totally abraded coating.

#### 6.3.2 Description

#### 6.3.2.1 Surface damage procedure summary

A defined eraser is mounted to an abrasion tool which allows the operator to perform several strokes on the lens surface. See Figure 6.

There are different degrees of severity by the number of strokes (10 – 40, the more the harder) and the force to the surface (usually 10 N, the higher the harder). The speed is 1 cycle = 2 strokes per second.

NOTE    A suitable equipment is available from Summers Optical in USA[2].

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2)    Summers Optical in USA, www.optical-cement.com/default.htm is an example of supplier of suitable equipment available commercially. This information is given for convenience of the users of this document and does not constitute an endorsement of this product by ISO.
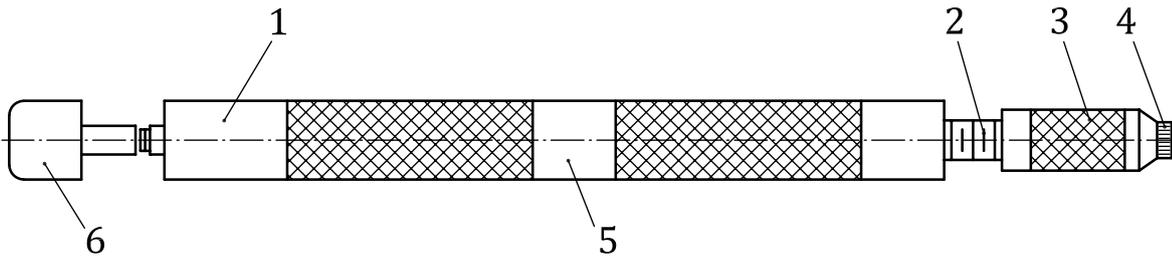
**Key**

1 indicator rod
2 plunger
3 chuck
4 eraser
5 body
6 cap

**Figure 6 — Eraser tool**

### 6.3.2.2 Method of assessment of surface damage

After rubbing the lens surface, it is visually examined by transmissive or reflective viewing against a fluorescent light source in front of a matt black background. See Figure 7.

Evaluation is done by comparing the tested lens with a set of defined samples with different quality. Usually, several lenses are tested to get a reasonable mean value as final result of the evaluation. Figure 8 shows an example of eraser test damage.



a) Reflection inspection      b) Side illumination inspection
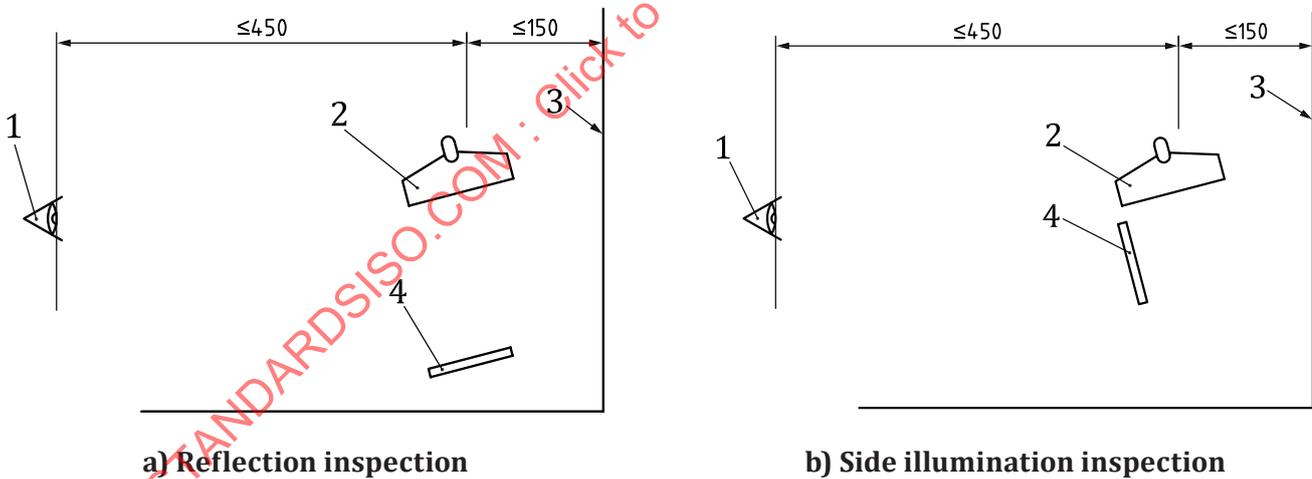
**Key**

1 observer
2 commercial fixture containing light source
3 matt black background
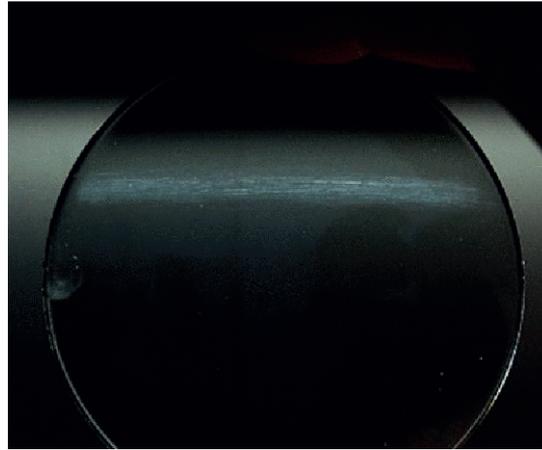4 specimen

**Figure 7 — Diagram of the visual assessment method**

**Figure 8 — Image of the surface damage**

### 6.3.3 Pros and cons

#### 6.3.3.1 Pros

— The test is easy to handle.

— The equipment is inexpensive.

— The expenditure of time is low.

— The kind of surface damage of tested lenses often is visually similar to light scratches on worn lenses.

#### 6.3.3.2 Cons

— The evaluation by visual examination is subjective.

— The reproducibility is medium.

— Changing the load on the abrasive media, the velocity or the number of cycles can result in different results of the test.

— This test method has not been shown to correlate with real-life abrasion resistance of lens surfaces.

## 6.4 Bayer test (Oscillating abrasive grain test)

### 6.4.1 Principle

The Bayer test is a well-known abrasion test in the spectacle lens industry and has been used since almost decades.

The test is not only used to compare different coating products or for development purposes but also as a quality control in day to day business.

The goal of the Bayer test is to determine scratch and abrasion resistance of coated or uncoated spectacle lens products. The Bayer ratio or number gives a quantitative value to the resistance.

### 6.4.2 Description

#### 6.4.2.1 Surface damage procedure summary

Both a test and a reference lens are exposed to an abrasive material at the same time. The lenses are placed with the convex side up in an oscillating pan while the abrasive material slides across. The number of oscillating cycles is not fixed but typically at least 300 up to 600 cycles are used. Figure 9 shows the schematic principle of the setup.
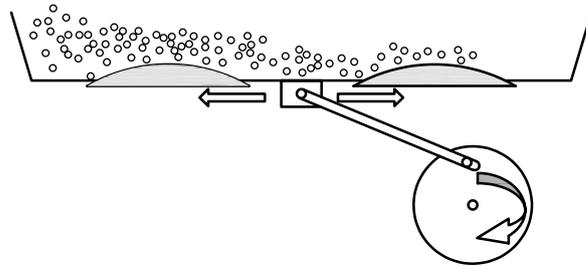


**Figure 9 — Schematic principle of Bayer test setup**

The mechanical stress will cause scratches on the exposed surface a certain opacity or haze level. After cleaning, the resulting haze can be measured on both test and references lenses by a hazemeter. The haze measurement is frequently done by using the method described in ASTM D 1003.

#### 6.4.2.2 Method of assessment of surface damage

Test assessment is made by calculating the Bayer ratio ($BR$) from the increase in haze of the test sample normalized against the increase of haze of the reference lens.

$$BR = \frac{\Delta H_{\text{reference}}}{\Delta H_{\text{sample}}}$$

where

$BR$                 is the Bayer ratio;

$\Delta H_{\text{reference}}$      is the increase of haze of the reference lens;

$\Delta H_{\text{sample}}$        is the increase of haze of the test sample.

As it is desired to show how much a particular coating is more scratch resistant, the comparative lens is always uncoated. Such reference lens normally used is an uncoated 1.5 index allyl diglycol carbonate (ADC).

Some influencing factors need to be carefully controlled with the Bayer test. Such factors are:

— The geometry of the test and reference lens;

— The abrasive material used (particle size, shape, weight, hardness);

— Stray light measurement;

— The type of reference lens;

— The type of Bayer test rig.

Recent investigations have shown that improvements can be made to the Bayer test. The analysis showed that most of the influencing factors are ruled out by the idea of using reference lenses, e.g.:

— Influence of number of cycles;

"The ratio stays constant within ± 1 once more than 200 cycles are applied."[3]

— Aggressiveness of abrasive material;

"...inherent referencing of the test works, we obtained Bayer ratios of 6 ± 0.5 independent of the aggressiveness of the abrasive material."[3]

whereas others need to be carefully watched like, e.g. the test rig itself. The authors of the study presented an approach that seems to be able to improve reliability, accuracy and repeatability.

### 6.4.3 Pros and cons

#### 6.4.3.1 Pros

— Well known in industry.

— Rather simple methodology.

— Neither complex nor expensive.

— Test variation is compensated in a certain range as both the lens under test as well as the reference lens are subject to the same variation.

— Non-subjective testing.

— Quantitative statement.

#### 6.4.3.2 Cons

— Results are often not comparable across different test setups.

— Availability and consistency of abrasive material (almost one supplier only).

— Differences in results while using different abrasive material (Alundum vs. other versions of ceramic granules).

— Differences in results while using different lots of the same abrasive material.

— This test method has not been shown to correlate with real-life abrasion resistance of lens surfaces.

## 6.5 Nano scratch (Diamond point loading device)

### 6.5.1 Principle

The principle is to damage the surface of a test sample by drawing a probe across it. The probe tip has a specified shape and made of diamond. The load on the tip can be either variable or fixed.

The resulting stresses in the surface can lead to different types of damage such as permanent deformation, cracking or chipping.

In addition to abrasion others parameters can also be monitored during the test for example the coefficient of friction.

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3) A. Neuffer et al., "Bayer Ratio Re-Visited", MAFO 3-15 (2015), pages 28-31

### 6.5.2 Description

#### 6.5.2.1 Surface damage procedure summary

The principle of the nano-scratch test is provided in Figure 10.
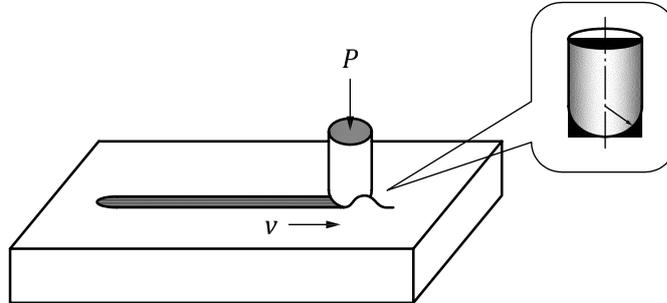


**Figure 10 — Principle of the nano-scratch test**

Two different testing approaches are generally used and can be combined.

The first approach, a basic method, utilizes a specified constant load applied to the probe, the tip of which is drawn across the surface at a specified speed. Multiple trials with different combinations of load and speed are conducted to characterize the scratch response of the test sample. Although this approach is more time consuming, the results can be more reliable.

With the second approach, the load on the probe is increased gradually during the trial while it is being drawn across the surface. The load range and speed of the probe are adjusted so that the predicted failure point occurs near the mid-zone of the trial.

The scratch response of lens surfaces (i.e. damage) depends on several parameters such as tip shape, load, orientation of application and velocity. Results can also be affected by environmental conditions (temperature, humidity, sample preparation) which might have potential effects on the coefficient of friction of the test sample.

#### 6.5.2.2 Method of assessment of surface damage

The damaged surface can be inspected visually but is more commonly analysed by performing image acquisition and processing. Scratches can also be characterized with an optical microscope and/or profile analyser device to measure location, width and depth.

Scratch analysis is based on the set of parameters (tip configuration, load and speed) at which the desired level of surface damage is first detected, where typically the load is the variable parameter in each trial. The key element in predicting the scratch resistant performance of a given lens surface is the combination of test results that involve variations in tip shape, speed and load across many trials.

The test method based on a diamond scratch requires highly sophisticated instrumentation capable of ensuring high accuracy and precision of the load application and speed of tip movement. In addition, high precision of the tip shape is required as this is essential to ensure reproducibility of the test method. One solution to reduce the effect of variation between tips is to perform comparative analysis between materials under the same controlled conditions.

### 6.5.3 Pros and cons

#### 6.5.3.1 Pros

— Control of main parameters.

— Good simulation of real-life circumstances leading to surface scratching.

— Quantitative analysis.

### 6.5.3.2 Cons

— Expert required for design of test and interpretation of results.

— Tip consistency (specifications, reproducibility).

— Complexity of model to characterize surface damage.

— Expensive equipment.

— Time consuming.

— This test method has not been shown to correlate with real-life abrasion resistance of lens surfaces.

## 6.6 Taber abrasion wheel test

### 6.6.1 Principle

The Taber Test is based on ASTM D1044 test. It was created for testing the durability and abrasion resistance of paint, by measuring the weight of the paint removed during the test. Later the test was modified and approved as an ASTM standard to test the "resistance of transparent plastics to one kind of surface abrasion by measurement of its optical effects" using haze measurements. The method has been referenced in numerous standards and specifications (including plastics, coatings, laminates, leather, paper, ceramics, carpeting, safety glazing, etc.).

### 6.6.2 Description

#### 6.6.2.1 Surface damage procedure summary

Taber abrasion testing is performed by mounting a flat specimen, either square or round, to a turntable platform that rotates two abrasive wheels over the specimen at a fixed speed and pressure (See Figure 11). One wheel rubs the specimen outward toward the periphery and the other, inward toward the centre. Haze (ASTM D1044) is measured pre-test and post-test to allow for comparison of the material properties. A wide variety of abrasive wheels are available depending upon the project goal.
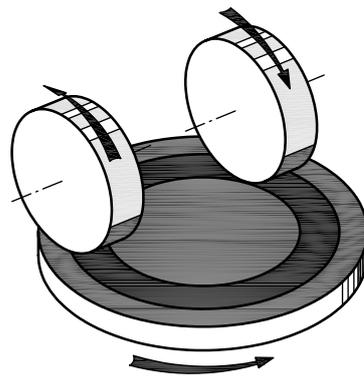
**Figure 11 — Schematic of Taber test**

Characteristic rub-wear action is produced by contact of the test specimen against the sliding rotation of the two abrading wheels. As the turntable rotates, the wheels are driven by the sample in opposite directions about a horizontal axis displaced tangentially from the axis of the sample. One abrading wheel rubs the specimen outward toward the periphery and the other, inward toward the centre while a vacuum system removes loose debris during the test. The wheels traverse a complete circle on the specimen surface, revealing abrasion resistance at all angles relative to the weave or grain of the