Assessing the Damage Resistance of a Coating

Introduction

Coil coated metal is used in many applications. In each of its uses, some fabrication of the painted metal coil is necessary. After fabrication, additional processes might be used as the painted product is brought to market. During these processes, the coated metal must be designed to withstand forces and matter that can create physical and aesthetic damage to the product.

All damage is at the least an aesthetic problem, or—at worst—presents a defect that could lead to a shortened lifetime for the product. This tool kit has been created in an effort to introduce the reader to the current science associated with the mechanics of damage, and the tools and methods available to assess a coating's resistance to damage.

There are many opportunities for damage to occur to a coated metal system, beginning at the point when the painted metal coil is wound-up after the painting and curing operation. Too much rewind tension could create pressure mottling; too little tension might lead to abrasion as one wrap of the coil moves against another. Many times these conditions are referred to as imprinting, flecking, picking or scuffing.

If the painted coil is transported "eye horizontal," pressure mottling can occur, since the weight of the entire coil rests on a small surface area. Coil coatings are routinely roll formed, brake formed, drawn, punched, notched, and processed in countless ways. Each of these processes represents an opportunity for damage to occur. In the case of building products, nested stacked panels produced at a fabricating plant are transported to a job site and once at the job, are now handled under the usual conditions seen at a construction site.

During the transportation step, the nested stack of panels will experience some amount of vibratory movement. The rubbing of the back side of a panel to the front side of another panel is an opportunity for wear. While at the job site, panels from the nested stack could be dragged—rather than lifted—from the stack as they are installed onto the building. When one panel is dragged over another, there is an opportunity for the edge of one to cut into the face of another; therefore, abrasive wear may take place. Many building panels are nailed or screwed to a support frame. During this process the coated metal system is pierced. In addition to resisting the damage of a piercing operation, coatings may be damaged from errant hammer strikes, a dropped tool, or a person walking on a panel with stones embedded into the tread of their work boots.

There are countless opportunities for a coating to be damaged from the time that it is coil coated until it is actually placed into service. Coil coated metal has been designed to resist this damage, but assessing the physical properties needed for a paint film to resist the various opportunities for damage is a daunting task. The branch of science that studies friction, lubrication and wear is known as tribology.

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For coil coatings, we are primarily concerned with two types of wear—Abrasive Wear and Adhesive Wear. Adhesive wear is concerned with a transfer of material from one surface to the other, or the formation of a particle that can then create wear. Abrasive wear is the result of two surfaces rubbing against each other, but where no material transfer is evident. Wear, however, cannot be easily categorized. In addition to adhesive and abrasive wear, there are other types of wear that have an impact on coil coatings (such as erosion wear from wind-blown particles of sand), or represent complex combinations of wear (such as fretting wear that results from small oscillating motion, which might occur, for example, as nested building panels, banded loosely to a skid, are trucked to a job site). This tool kit, therefore, introduces the reader to the science of Tribology, while, at the same time, limiting the discussion to those types of common modes of potential damage that a coil coated metal system experiences.

Tribology

Tribology is a science that studies the interaction of surfaces. These surfaces might be the piston in an internal combustion engine, or the lubricant that attempts to minimize the influences of friction between the piston and cylinder wall. Tribology is the study of friction, lubrication and wear. These factors cannot be neatly separated into individual issues, since interactions between surfaces are not trivial. They involve complex relationships among myriad factors, but this tool kit attempts to minimize the complexity.

Abrasive Wear

Abrasion resistance is the ability of a material to withstand wear. Although wear and abrasion are often used interchangeably, there is a difference. Abrasion is the action (or cause); wear is the result (or effect). ASTM defines abrasion as “the wearing away of any part of a material by rubbing against another surface”.

Abrasion wear is caused by mechanical action of surfaces rubbing against each other, resulting in the loss of material. There are many types of wear which are defined by the type of motion between the surfaces. Wear is often a natural consequence of two surfaces moving in relative motion to each other which interact in a largely unpredictable manner.

Wear – Asperity Interaction

Although surfaces may appear to be smooth, they actually consist of small bumps called asperities, which are the sites of actual contact between the two surfaces (see Figure 1). The interaction of these asperities leads to the loss of material, through wear mechanisms such as abrasive wear, adhesive wear, corrosion, and fatigue. The main wear mechanisms described in this tool kit are associated with damage resistance of coatings resulting from abrasion and adhesion wear.

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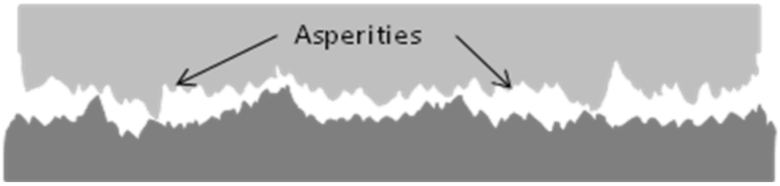

Figure 1 - Asperities on surfaces

Abrasive wear occurs as a result of the ploughing out of softer material by a harder surface resulting in scratches and wear particle formation. Two mechanisms of abrasive wear exist, 2-body and 3-body, which depend upon the position of the harder surface. If the rough hard surface slides against the softer surface (see Figure 2), this is known as a 2-body wear mechanism, for example the use of sandpaper.

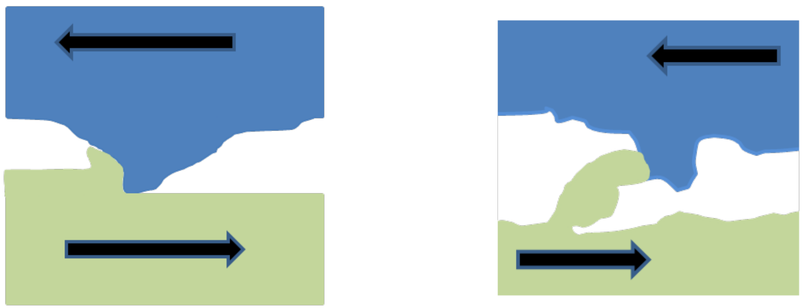

Figure 2 - 2-body abrasive wear mechanisms

A 3-body wear mechanism occurs when loose hard particles slide between moving surfaces as shown in Figure 3. These particles can be found in the working environment, or as a product of corrosion, which is often abrasive in character. Further wear results in the formation of wear particles which remain trapped between the surfaces and can accelerate 3-body wear mechanisms.

Figure 3 – 3-body abrasive wear mechanisms

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The three commonly identified mechanisms of abrasive wear are

- Ploughing, when material is displaced sideways from the wear track, resulting in groove formation that does not involve direct material removal.

- Cutting, when material is separated from the surface in the form of primary debris or microchips

- Fragmentation, when material is separated from a surface by a cutting process and the indenting abrasive causes localized fracture of the wear material resulting in additional material removal.

These mechanisms can work individually or simultaneously to cause considerable damage to a surface.

Scratching and Scratch Resistance Testing

Any damage to a coil coating that creates a physical defect, but where no material is broken free from the coating, is considered abrasive wear. One measure of the abrasive resistance of a material can be obtained using a scratch test. This involves moving a stylus across a coated surface which results in an array of defined scratches. The stylus apical angle (see Figure 4A), load and velocity can be systematically altered so that a comprehensive picture of the resistance to scratches can be obtained. By measuring the width of the scratch, using techniques such as the white light interferometer, the scratch hardness can be determined and scratch hardness maps can be constructed which give an indication of the elastic and plastic response of the coating under particular loads and conditions. Through this, comparisons are made between different coatings and substrates which provide quantitative results under a controlled environment. Figure 4B shows a schematic of the scratch test.

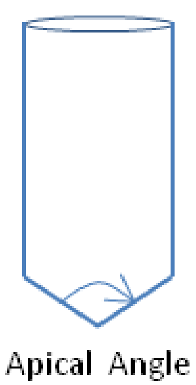

Figure 4A – Apical Angle

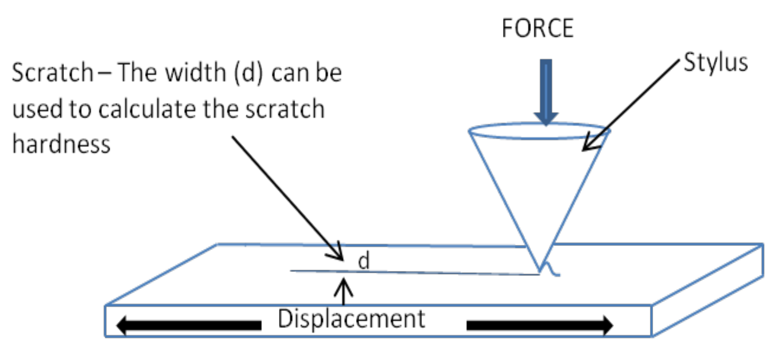

Figure 4B - Schematic of a scratch test

The scratch hardness is calculated using the residual scratch width; therefore, the method only represents the permanent plastic deformation and not the instantaneous response of the elastic and plastic deformation combined. The technique cannot be used for a truly elastic material which does not leave a residual scratch, as an unrealistically infinite hardness will be calculated.

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The scratch hardness is calculated using the equation:

Scratch hardness = $q \frac{4\,F_N}{\pi d^2}$

where q is the plasticity correction, F_N is the normal force (N) and d is the scratch width (m).
The scratch response can significantly differ with a change in load or stylus apical angle, moving from an elastic response where no residual scratch is visible, to a fully plastic response where the residual scratch is obvious. The rate of scratching can also have an effect on the result.

An example scratch map is shown in Figure 5 which shows a near-elastic response at high stylus apical angles and low loads, and a plastic response at low stylus apical angles and high loads. Although this Figure shows the results of a 'real' material, it shows a very simple response, and in general coatings show more complex behaviour.

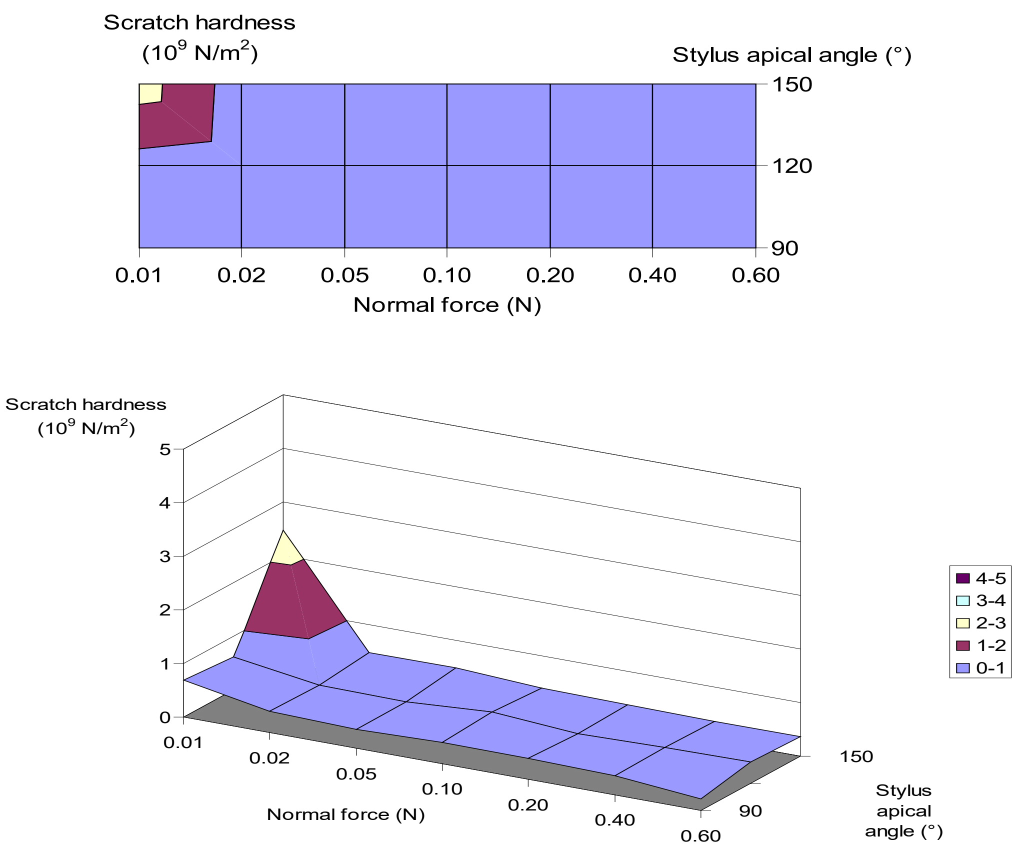

Figure 5 - Example of 3D surface map and contour plot.

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Adhesive Wear

Adhesive wear occurs as a result of intimate contact between surfaces. Under load, contact occurs at asperities, which plastically deform until the area of contact is able to support the applied load. In the absence of a surface film, bonding occurs at the asperity junctions, which during relative motion can result in material transfer or often the transferred material comes off and particle formation occurs.
With further movement, the transferred material may transfer back to the original surfaces (see Figure 6), in which case material is not lost; however, the formation of a wear particle results in permanent loss of material. Adhesive wear can be reduced if the attraction between the two surfaces is reduced as a result of surface contamination and oxide layers. Adhesive wear can occur on both rough and smooth surfaces.

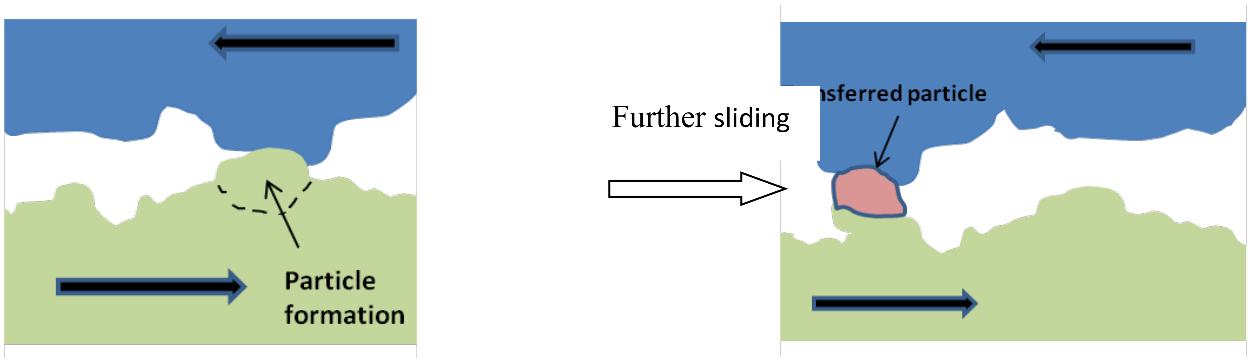

Figure 6 - Adhesive wear

Erosion wear is caused by the repeated impact of particles carried in a liquid or gas which results in cutting and deformation to the surface. The wear rate of erosion is strongly affected by the angle of incidence of the particle, with differences in wear rate seen for samples made from ductile and brittle materials. For ductile materials the highest wear is found for angles of attack around 30º where an abrasive cutting mechanism is observed. As the angle of attack increases the wear mechanism moves towards fatigue where repeated deformations of the surface result in the formation of wear particles. For brittle surfaces the highest wear is found at a 90º angle of attack where crack and wear particles are formed

Fretting wear is caused by micromotion between two surfaces. The damage is often induced under load and is a result of vibration which results in adhesive wear, and the formation of wear particles. In metal substrates, this micromotion can lead to corrosion, the products of which are often harder than the base substrate, and subsequently abrasive wear of the material occurs. In the coil coating industry, this defect is most often seen as transit abrasion damage.

Abrasion Resistance Testing Methods

Many of the testing methods can be used to rank materials in order of their abrasion resistance. Testing methods include:

- Pencil hardness
- Falling sand abrasion test
- Taber abrasion test
- RCA Abrader
- Stone Chip

From these tests, the abrasion resistance can be calculated by either an instantaneous effect or the loss in weight of material following either a specified number of abrasion cycles, as a weight loss per cycle, or as the number of cycles required to remove a unit amount of coating thickness. The analysis of an abrasion test is often through visual analysis of the surface/coating and can be described as a change in appearance or loss of material. A pass/fail criteria may be used to rank materials/coatings in order of their resistance. An optical micrometer or instrument such as a profilometer may be used to assess the depth of material lost.

Pencil Hardness Test

A bane to any technologist in the coatings industry, this simple, quick, inexpensive test is considered invaluable by many in the industry. Drafting pencils, designed and controlled for the darkness of their color, have been used, specified and accepted by many in the industry where coatings are used. The “hardness” of the leads is not controlled. The meaning of the results is often brought into question, yet there is some—albeit limited—value in this test. It does give a crude measure of the cutting (damage) resistance of a coating, but is plagued with operator variability and consistency of the “hardness” of the lead (which are *never* controlled for hardness). Pencil hardness must never be the only test used to assess the quality of a coil coating, and a wide range of hardness values should be specified to more accurately show the lack of precision of this test. (see ASTM D3363 and NCCA Toolkit 16)

Falling Sand Abrasion Test

This test involves allowing abrasives to fall from a specified height through a guide tube onto the coated substrate which must be a plane rigid surface. The abrasive is allowed to fall until the substrate becomes visible. The amount of abrasive per unit film thickness is reported as the abrasion resistance. Both silica sand and silica carbide are often used. This test has limited pertinence in the coil coating industry; however, many specifications have a legacy of requiring this test. (see ASTM D968 and Figure 7)

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Figure 7 - Falling Sand Abrasion Test

Taber Abrasion Test

The Taber abrasion test is a rotary platform abrasion tester which is used to test the abrasion resistance by producing a characteristic rub wear action. The flat sample is fixed to turntable which rotates at a fixed speed and a specified pressure is applied to the coated substrate through two abrasive wheels. The wheels move in opposite directions and the loose debris is removed via a vacuum system. An important feature of this instrument is the wheels traverse a complete circle on the specimen surface, revealing abrasion resistance at all angles relative to the weave or grain of the material. Past work suggests that this technique tests the brittleness of a coating, rather than actual abrasion resistance. Microscopic inspection of a Taber abraded panel shows a micro cross hatch pattern. (see ASTM D4060 and Figures 8A and 8B)

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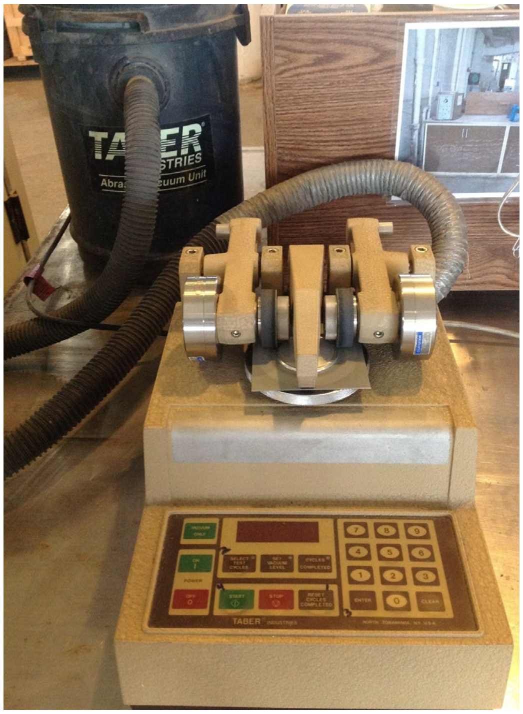

Figure 8A - Taber Abrasion Tester

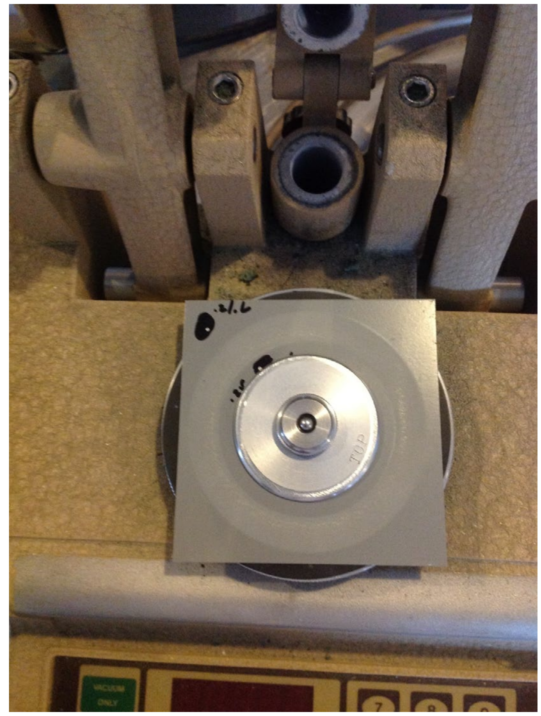

Figure 8B - Sample Mounted on Taber Abrader

RCA Abrader

The RCA abrader is a point contact abrader which can be used to test many shapes and sizes. As with other abrasion testers the result is often identified by visual inspection of the wear area to see whether the underlying substrate is visible. It is highly accelerated test that can simulate wear conditions and provide an idea of the abrasion resistance of a coating. In this test, the coating is actually rubbed (worn) away. There is no evidence of micro-scratching in this test. (see ASTM F2357 and Figure 9)

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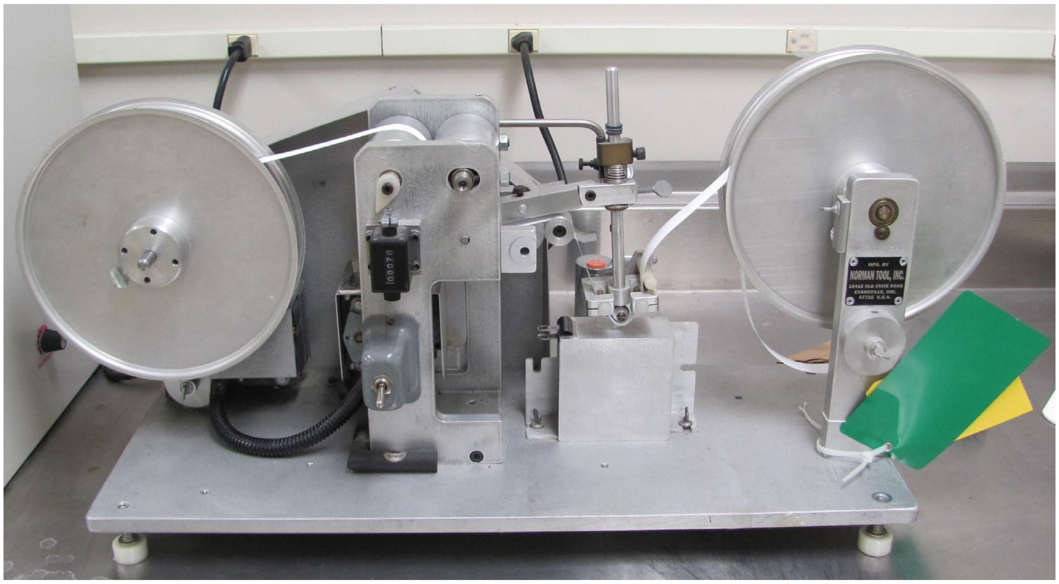

Figure 9 - RCA Abrader

Stone Chip (Gravelometer)

The Stone Chip test, more commonly called the Gravelometer test, is a direct impact test using gravel as the impact media. Unlike a direct impact test using a single impact from a metal indenter, the gravelometer test impacts a target with approximately 300 stones. The size, depth and density of the chips created are used to compare a control with the test specimen. This method is intended to mimic the chips roadway gravel causes when thrown against a car body. (see ASTM D3170)

Influencing factors

The resistance to abrasion can be affected by many factors such as the shape, hardness, impact velocity, and impingement angle of the abradant. Angular blocky particles (sharp-edged stones) are more likely to cause wear of the surface than round smooth ones, with larger harder particles causing more wear than small softer particles. If the wear particles are brittle in nature, they may break causing additional particles and cutting edges. The contact pressure, sliding speed state of lubrication, and the temperature and humidity of the environment may all be contributing factors to the abrasion resistance of a particular sample.

Although abrasion resistance tests cannot replicate exact real life situations, they provide an indication of the resistance of a surface. Laboratory tests provide a uniform way to measure the resistance allowing different materials to be compared by testing them in the same controlled environment. It also allows a greater number of samples to be evaluated in an economical way. Abrasion tests can be used to check for defects and consistency in characteristics and quality of a surface, allowing surfaces and materials to be ranked in order of their abrasion resistance.

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