SCOTCH-BRITE™ PRECISION SURFACE CONDITIONING DISCS

Technical Whitepaper

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3M

SCOTCH-BRITE™ PRECISION SURFACE CONDITIONING DISCS

ABSTRACT: 3M Company's new Scotch-Brite™ Precision Surface Conditioning Disc is the newest innovation in the surface conditioning category. This family of discs includes new technology, specifically the new product contains proprietary 3M Precision-Shaped Grain (PSG) as well as other innovative premium materials. The 3M Precision-Shaped Grain, as well as other enhanced raw materials used to make the Scotch-Brite™ Precision Surface Conditioning Discs, yield a high finishing rate and a longer life than leading competitive nonwoven discs.

Abrasive products made by 3M Company have been sold into both the industrial and home improvement markets since 1905. Today's abrasive products are generally categorized in three types: coated, bonded and nonwoven. Coated abrasives are the most easily recognized as they are ubiquitously known as sandpaper and can be found in most home improvement stores. Bonded abrasives can be subcategorized into conventional bonded and precision bonded abrasives. Conventional bonded abrasives can range from inches (a few centimeters) in diameter, meant to be used on portable tools, to multiple feet (meters) in diameter. Nonwoven abrasives are a class of products where the abrasive grain is coated onto a mat of interlocking, nonwoven fibers. The fibers may be naturally occurring (e.g., hemp) or synthetic (e.g., nylon, polyester) which is more common for industrial abrasives.

3M invented and was the first to market,[1] in 1958, with an innovative new form of abrasive products which was based on a nonwoven web of fibers. These nonwoven abrasive products expanded the range of applications for abrasive products and are marketed and sold under 3M's well known Scotch-Brite™ brand. Nonwoven abrasives can take many shapes and forms. The simplest example is a hand pad which is abrasive coated on a lofty nonwoven fiber web. To expand the applications of nonwoven abrasives, the mineral-coated nonwoven webs can be cut into sheets, pressed and cured to make a dense construction used as wheels.
This layered product construction is known as unitized wheels, and they are used for deburring and finishing applications. The nonwoven webs can also be wrapped tightly as a bun and cured. This makes a dense wheel which is spun and run directionally. The bun can then be cut across the diameter into the desired thickness making convolute wheels. Convolute wheels are used for deburring, polishing, and finishing.

Another type of nonwoven product is known generically as surface conditioning products. In this construction the lofty nonwoven fiber web is needle-punched to a woven scrim or cloth.

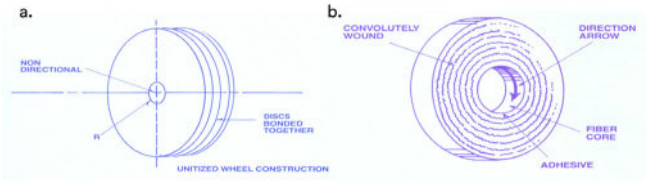


Figure 1: *Construction of a) unitized and b) convolute wheels.*

The woven backing gives strength and integrity to the nonwoven web to hold up to the rotational speeds of handheld pneumatic and electric grinders. The needle-punched web is then coated with resins and abrasive mineral. These surface conditioning webs are then converted into either belts or discs. The discs can range in diameter from less than an inch to as wide as the web, in many cases more than 36 inches (1 m). The most popular size discs are less than 7 inches (180 mm) in diameter and fit on portable right-angle grinders. While discs grew in popularity, many new attachment types were made to connect the disc to the grinder quickly, safely and efficiently to make the operator experience seamless. Some of the most popular attachment

methods are hook-and-loop, 3M™ Roloc™,[2] attachment systems or TN nuts.

3M Abrasives Systems Division introduced the revolutionary 3M Precision-Shaped Grain[3] (PSG) in a 982C coated fiber disc and a 984F belt in 2009. The revolutionary performance of PSG in coated abrasives was quickly adopted into 3M™ Cubitron™ II branded portable bonded cut-off wheels and grinding wheels. Nonwoven abrasives have been a more cautious adopter of PSG, though. When first commercialized, 3M Precision-Shaped Grain was only available in large, coarse grits i.e., 36+, 60+ and 80+.[4] Generally, nonwoven abrasives are not made to remove large amounts of material but are designed for finishing work which does not entail drastically changing the profile of the workpiece. Gradually, smaller PSG was developed and the first adoption of PSG in nonwoven abrasives was in a unitized wheel construction: Scotch-Brite™ Deburr and Finish Pro.

The newly released Scotch-Brite™ Precision Surface Conditioning Disc family is the first time 3M Precision-Shaped Grain has been used in this nonwoven product type. The construction of the new product is patent pending[5] and realizes the high performance expected from products containing PSG in a nonwoven disc form. The 3M Precision-Shaped Grain, as well as other enhanced raw materials used to make the Precision discs yield a high finishing rate and a longer life than leading competitive nonwoven discs. Scotch-Brite™ Precision Surface Conditioning Discs set a new standard in surface conditioning performance. These premium multi-purpose discs are designed to streamline surface conditioning processes including cleaning, blending, deburring and finishing. Typical substrates include aluminum and soft metals, carbon steel and stainless steel, with applications ranging from coating and corrosion removal to refining and post-cast processing.

MATERIALS AND METHODS

End-of-life disc testing was completed according to the following conditions. Three-inch diameter Roloc™ surface conditioning discs were tested using an internally constructed robotic testing machine (X-Y Table), which moves in both the X and Y directions. The test method exerts 7 lbs (31.1 N) of force and using a servo motor while the rotational speed is held at a constant 10,000 RPM. 304L stainless steel, 1018 carbon steel, and 6061 aluminum workpieces were acquired from K-Sales Inc. Minneapolis, MN. The workpieces were 6”x14”x0.75”, 6”x14”x0.75”, and 6”x14”x1”, respectively. Discs were attached to a hard 3M Roloc™ back up pad, PN45091. Under the above force and RPM discs were systematically moved across the surface of the respective workpieces for one minute. The weight change of the workpiece was measured after each minute of testing. The disc mass was measured every 8 minutes and at the end of the disc life. The disc angle during the test is held constant at 5° relative to the plane of the workpiece.

Surface finish of the workpiece was determined using a Mahr Pocket Surf IV profilometer. Surface finish measurements of the workpiece were taken after minute 1 (initial surface finish) and after minute 8 (final surface finish). Surface finish is measured on 5 discrete points of the workpiece. The X-Y Table test method for surface finish used the settings outlined above except 5 lbs (22.2 N) of force and a rotational speed of 9000 RPM was used.

Smear testing was conducted on samples prepared using the X-Y Table. 304L stainless steel coupons, 6”x4”x0.075”, with a 2B finish were acquired from K-Sales Inc. Minneapolis, MN. Three-inch discs were moved in a linear direction across the workpiece at a traverse rate of 2.5 inches per second. The force applied was 7 lbs and the rotational speed was held constant at 10,000 RPM. A 3M proprietary vision system has been used to capture images of the smear defects. The imaging system enables the smear analysis of the entire stainless steel coupon. Smear defects can be revealed due to the contrast or the smear relative to the background. As can be seen in **Figure 2**, the smear defects appear as dark curved lines formed in parallel to the groove lines.

Disc flexibility was recorded using an MTS Insight 100. Three-inch diameter Roloc™ discs were suspended between two parallel plates with a 2” gap. A force of 10 or 5 lbs was applied to unused and used discs, respectively. Once the defined load was reached the deflection of the disc was recorded.

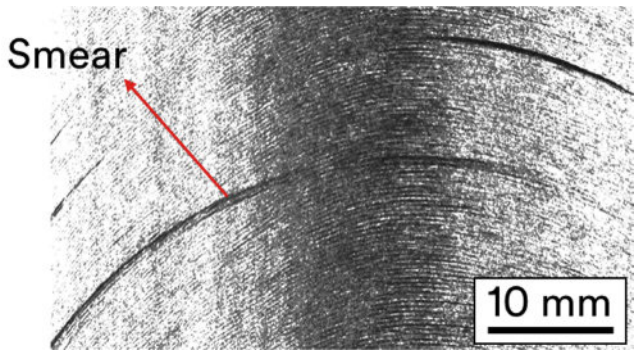


Figure 2: *Image of a stainless steel workpiece containing multiple smear defects.*

3M surface conditioning disc samples were obtained from 3M Company, Maplewood, MN. Disc families from 3M include Scotch-Brite™ SC, AL, PD, SL, LGB and the new Precision line. Surface conditioning discs from SIA, Norton, and Bibielle were obtained from distributors in the United States, United Kingdom, Germany, and Australia, Table 1. Testing data throughout was gathered by testing 15 discs, 5 discs from 3 separate sources (e.g., distributors/material lots).

Table 1: *Product IDs and sources for three-inch (75 mm) diameter discs with type R buttons.*

Company	Norton Rapid Prep		Bibielle		Sia 6270 Web	
Grade	Product ID	Source	Product ID	Distributor	Product ID	Distributor
MED	66261017522	Abrasive Specialties (USA)	BIBDR1341	United Kingdom	6884.4655.4921	Australia
		Grainger (USA)		Lehigh Valley (USA)		Abrasive Specialties
		AA Abrasives (USA)		Germany		UK (MSC)
CRS	66261009194	Abrasive Specialties (USA)	BIBDR1340	United Kingdom	6884.4655.2921	Australia
		Grainger (USA)		Lehigh Valley (USA)		Abrasive Specialties
		AA Abrasives (USA)		Germany		UK

RESULTS AND DISCUSSION

3M's new Scotch-Brite™ Precision Surface Conditioning Disc is the newest innovation in the surface conditioning category. This family of discs includes new technology, specifically the new product contains proprietary 3M Precision-Shaped Grain (PSG) as well as other innovative premium materials. Performance of surface conditioning discs is generally attributed to long disc life, high and consistent cut-rate, surface finish on the part, and disc flexibility/conformability. Consideration is also given to the performance on multiple substrate materials. Performance of a disc on a specific material e.g., stainless steel, can be finely tuned-in for that substrate. The Scotch-Brite™ Precision Surface Conditioning Disc family is targeted to have a high performance on multiple substrates and is subsequently balanced to have good performance on aluminum, stainless steel and carbon steel substrates.

Branding, Descriptors, Appearance and Packaging

The launch of Scotch-Brite™ SC Surface Conditioning Discs, thirty plus years ago, also evoked the correlation between the color of the non-woven disc and the grade. Over time competitive manufacturers have adopted 3M's grading color scheme and it has become a recognizable industry standard. Commonly a black colored disc signifies an extra coarse grade, brown conveys the coarse grade, a maroon color implies a medium grade, green represents a fine grade disc, and blue is attributed to the very fine disc grade.

The Scotch-Brite™ Precision Surface Conditioning Disc family holds true to the color grading standard; however, the visual appearance of the discs has been enhanced with bolder and brighter color pigments. The new intensified color pattern offers the benefits of product recognition and brand differentiation, **Figure 3**.

In conjunction with the modernized colors of the discs, an icon has also been added to the product. The triangle icon, **Figure 4a**, symbolizes the 3M Precision-Shaped Grain that comprises this disc family and along with the vivid colors, provides additional product and value proposition discernment. The word precision acts as a technical descriptor as well in the discs' marketplace formal name, Scotch-Brite™ Precision Surface Conditioning Disc.

Alongside the enrichment of color to the physical discs themselves, there have also been beneficial visual modifications to the packaging for the Roloc™ disc form of the Scotch-Brite™ Precision Surface Conditioning Disc family. The packaging, **Figure 4b**, stands out against others with the black and silver industrial color design. In addition to the look of the Roloc™ boxes, the label on the inner packaging has also been updated to include the ability to call out to consumers which grade of disc is in each inner package. Depending on which grade is in the inner package, a black box encompasses one of the five colors illustrated on the label.

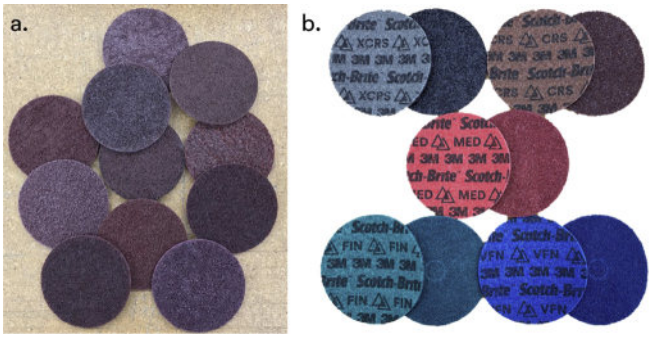


Figure 3: *a) An assortment of various families and manufac-turer's medium grade surface conditioning discs. b) Preci-sion Surface Conditioning Disc color schematic and brand printing on backside of the disc.*

This upgrade to the label was an answer to customers asking for increased ease and efficiency in identifying which grade of product was in each box. In addition to the new visual packaging cues, centered around improving the customer process, is a new perforated modification, allowing for fast and easy dispensing of the discs, **Figure 4b**.

Figure 4: *Scotch-Brite™ a) Precision descriptor symbol. b) new, enhanced packaging.*

End of Life Test Results

The X-Y Table was designed to reproducibly replicate the performance of a surface conditioning disc product on the target substrate. The disc angle, force and RPM chosen were selected to mimic the disc use by an average operator in the field.

Discs used in the field are used until the disc can no longer be run or does not complete the job in an expedient manner.

$$End\ of\ Life\ is\ \frac{Final\ Cut\ Rate}{Initial\ Cut\ Rate} = 50\%$$

$$Final\ cut\ rate = \Delta last\ 3\ cycles$$

$$Initial\ cut\ rate = \Delta first\ 3\ cycles$$

Equation 1: *End of life for a disc abrading 6061 aluminum is determined by the above equation.*

The disc's "end of life" is defined as 50% of the initial cut-rate of the disc according to Equation 1, where the initial cut-rate is the average cut-rate over the first 3 minutes of use, and the final cut-rate is the average of the last 3 minutes of use.

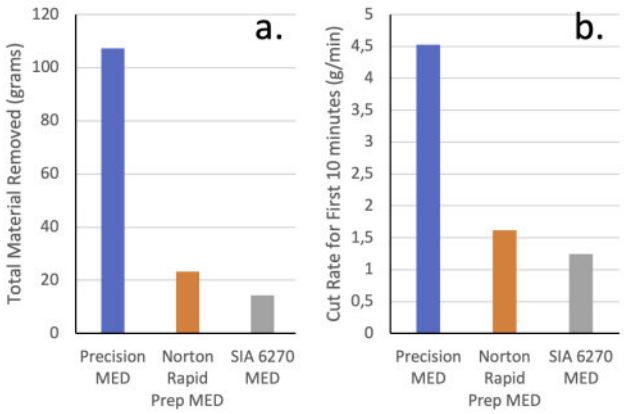


Figure 5 *a) Shows the total amount of material (aluminum) removed at the disc's end of life. b) Illustrates the average cut-rate per minute for each disc type in the first 10 minutes of testing.*

Scotch-Brite™ Precision Surface Conditioning Discs have five grades in the family: Extra Coarse (XCRS), Coarse (CRS), Medium (MED), Fine (FIN) and Very Fine (VFN). Medium discs are commonly used on aluminum substrates and the performance of Precision MED discs were tested and compared to the performance of competitive discs. Five discs from three lots of each disc type were tested to give statistical significance to the analysis.

In **Figure 5a** the cumulative cut of the discs is recorded. Each set of discs was run until the end of life was determined. Using Minitab statistical software, Precision MED discs demonstrate a 3X higher total cut on aluminum than competitive products with a 95% confidence interval. The cut-rate of the Scotch-Brite™ Precision Surface Conditioning Discs was also much faster compared to Norton Rapid Prep and Sia 6270, **Figure 5b.**

Precision Surface Conditioning Discs were also compared to other families within the Scotch-Brite™ portfolio: SC, AL and PD. The families chosen are all targeting similar low-pressure applications in the general metal fabrication and aerospace markets.

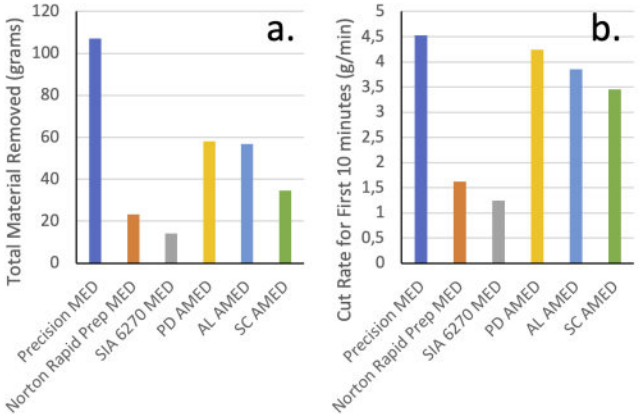


Figure 6: *Shows a) the total amount of material (aluminum) removed at the disc's end of life and b) the average cut-rate per minute for each disc type in the first 10 minutes of testing for Scotch-Brite™ and leading competitors.*

Figure 6 shows that all Scotch-Brite™ families' medium grade discs outperform both Norton Rapid Prep and SIA 6270 discs relative to the total amount of material removed by the end of the disc life and the average cut-rate over the first 10 minutes of use. PD, AL and SC all have fast cut-rates which are measurably lower than Precision discs, but the difference would likely be imperceptible to the average operator. The faster cut-rate of the Precision discs can be attributed to the PSG incorporated into the construction of the disc.

The significant improvement in the Precision family of discs is the high amount of total material removed

at the end of the disc life, **Figure 6a.** Nearly 2X more material was removed at the disc's end of life compared with Scotch-Brite™ PD, AL or SC. The innovative construction, in addition to PSG, is attributed to this improvement.

To illustrate the performance of the surface conditioning discs over the duration of the end-of-life X-Y Table test, the data is plotted according to **Figure 7.** The amount (grams) of material removed per cycle (minute), or part is shown. As discussed above, the cut-rate of Precision, AL, PD and SC are all much higher than Norton Rapid Prep or Sia 6270.

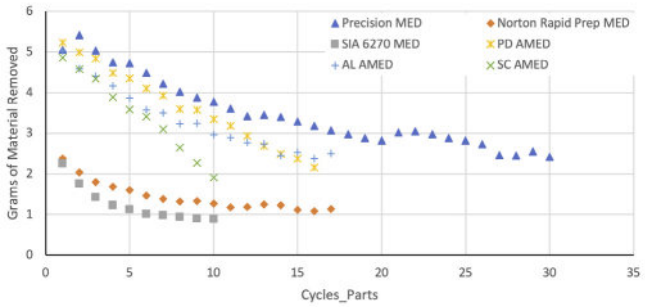


Figure 7: *The amount (grams) of material cut during each one-minute cycle is illustrated for Scotch-Brite™ Precision, AL, PD and SC. Scotch-Brite™ products are compared to Norton Rapid Prep and SIA 6270 discs.*

In addition to the faster cut-rate, Precision Surface Conditioning Discs outlast all other discs, lasting almost 2X longer under these test conditions. Compared to other tested discs, more material can be removed using one Precision Surface Conditioning Disc which means less time changing discs and fewer discs to discard at the end of the job for an operator, contributing to less waste.

Surface Finish

Nonwoven abrasives used in the metalworking marketplace are known to refine materials, leaving them with a desired final appearance/finish. The expectation of an acceptable finish will change based on subsequent process steps. Two common goals for finishing with nonwoven abrasive discs are to either prepare the surface for a coating, such as paint, or to achieve a specific surface finish on stainless steel. When the application is preparing the surface for paint/powder coat, a lower surface finish minimizes the required coating thickness at which the surface roughness does not show through the coating. In addition, many industries have a specification for surface finish on the part before powder coatings can be applied. When the application is refining the finish of stainless steel, it is common to have finish requirements, such as a scratch profile Ra value at or below different thresholds. For instance, 32 µin (0.8 micron) and 16 µin (0.4 micron) are two common finish threshold requirements that are used in many industries such as food & beverage and pharmaceutical processing equipment manufacturing. The surface finish that can be expected from (or is delivered by) each grade of Precision discs is shown in **Figure 8.** Error bars were multiplied by three for illustrative purposes. The error bars represent 3 different lots of material and 5 discs from each lot. Data shown in **Figure 8** should be used as a guide only — the surface finish imparted on a material is highly dependent on the method used to finish the surface. To name a few dependencies: angle of disc to workpiece, tool RPM, applied force, traverse rate and traverse direction have all been documented to influence surface finish. In addition, the initial surface finish from a new disc is expected to be coarser than after the disc has been used or "broken in." **Figure 8** shows the initial surface finish after the disc has been run on the substrate for one minute using the X-Y Table test.

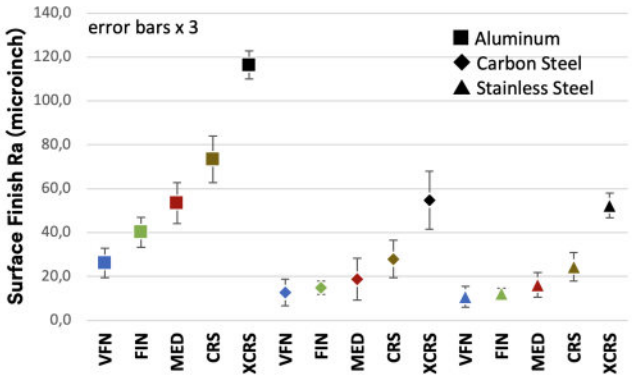


Figure 8: *Surface finish of Scotch-Brite™ Precision Surface Conditioning Discs on aluminum (¢), carbon steel (u) and stainless steel (p).*

Smear Testing

Abrasive products can sometimes leave a residue on the workpiece being finished. This causes the operator to have to perform some rework on the workpiece or require the operator to clean the workpiece in a second step. The residue can occur in a range of significance and for a variety of reasons; for example, from a sub-optimally designed abrasive product, use of the product beyond its useful life, or from misuse of the product.

While smear can occur on any metal substrate it is most prevalent/apparent on stainless steel. Preventing smear is usually attempted by running grinders at lower RPM

or applying less force when grinding; both of which can slow down the process of finishing a job.

The Scotch-Brite™ Precision family of discs were tested against competitive discs for the amount of smear (residue) that is left on a pristine stainless-steel work-piece. Coarse grade discs were chosen for the smear testing on stainless steel panels with a 2B finish. Smear can generally be easily identified by the naked eye, but it is notoriously hard to quantify smear. 3M uses a propriety vision system to take images of stainless steel surfaces and, through image processing shown in **Figure 9**, smear marks can be detected and then quantified using stereology methodology[6]. Using stereology, the average total length of the smear defects per unit area for each testing sample can be quantified. First, a series of equally spaced parallel vertical lines was superimposed on the image. The number of points of intersection between the test lines and the smear defects divided by the total length of the lines gives the P_L value. The average total length of the smear defect per unit area, L_A, can be estimated using the following equation:

$$L_A = \frac{\pi}{2} P_L$$

Equation 2: *Calculation for the average total length of a smear defect on a workpiece.*

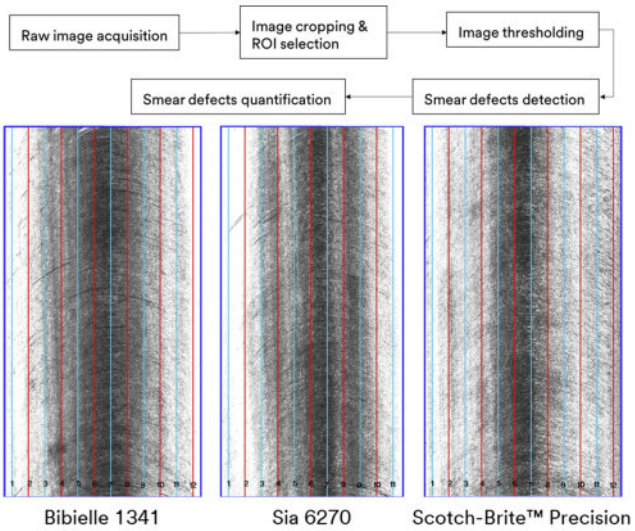


Figure 9: *Flow chart of the smear analysis process. Sample images of stainless steel coupons with imposed vertical lines prepared for smear analysis.*

The smear from Scotch-Brite™ Precision CRS, Sia 6270 CRS, and Bibielle CRS discs were compared using this method. Five discs from three separate lots were analyzed and the results were averaged. The results are shown in **Figure 10.**

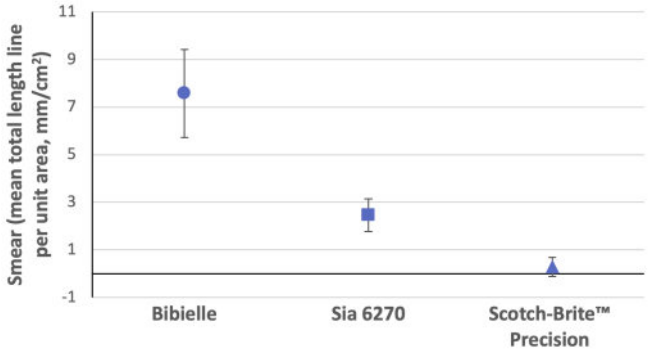
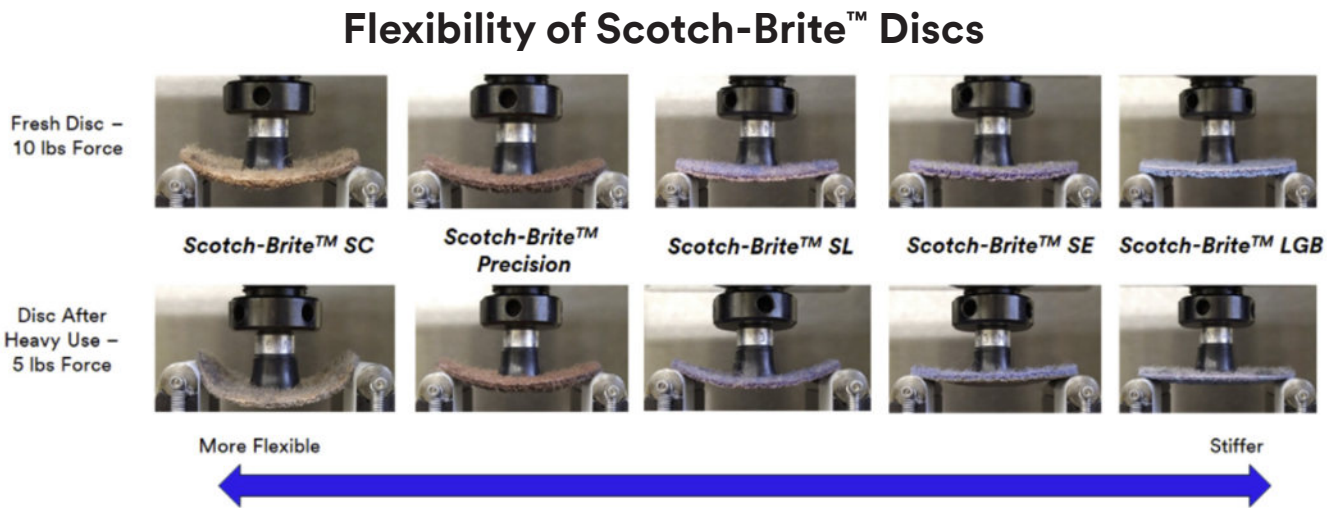


Figure 10: *The average total length of the smear defects per unit area.*

Disc Flexibility

A metric by which nonwoven (surface conditioning) discs are evaluated by operators is the flexibility of the disc. The flexibility of the system is also affected by the selected backup pad as well. For example, 3M offers soft, medium, hard and extra-hard Roloc™ backup pads to accommodate a range of customer preferences and applications.

To evaluate the inherent flexibility of a variety of 3M nonwoven discs, a 3-point bending test was used on 3” diameter Roloc™ discs mounted in a ~1” diameter holder. The discs were mounted onto a load frame (MTS Insight 100) and driven at a rate of 20 mm/min onto round bars with a span of 2” (50.8 mm). The discs and set-up are shown in **Figure 11.** Unused, or “fresh” discs were loaded to a force of 10 lbs (44.5 N). Discs were then tested to end of life as described above (labeled “Heavy Use” in **Figure 11**) and then loaded to a force of 5 lbs (22.2 N) to show the qualitative flexibility of the different Scotch-Brite™ products.



Performance on Stainless Steel

Disc performance on stainless steel was evaluated using a similar method as was used on aluminum substrate. Unlike aluminum, the testing was stopped after twelve minutes. Under this test method, the disc cut-rates converge after 12 minutes and are relatively constant for a long period of time (>30 minutes). The differences in the performance of the discs are most noticeable within the first 12 minutes of testing.

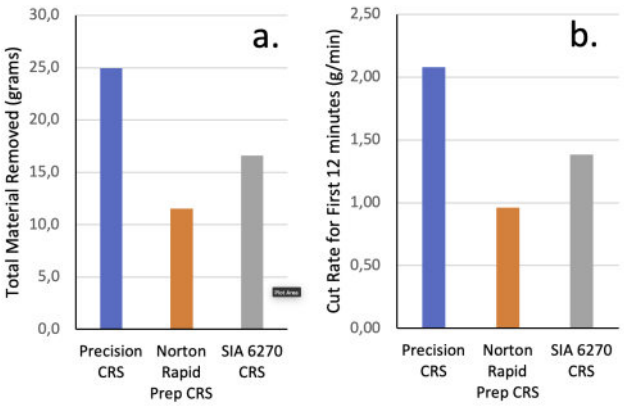


Figure 12: a) Shows the total amount of material (stainless steel) removed after using the disc for twelve minutes. b) Il-lustrates the average cut-rate per minute for each disc type after the first 12 minutes of testing.

The cumulative amount of material removed from the workpiece is shown in **Figure 12** for Scotch-Brite™ Precision, Norton Rapid Prep, and Sia 6270 coarse grade discs. Precision Surface Conditioning Discs removed 1.4X more material than Sia 6270 and ~2X more material than Norton Rapid Prep discs. The average cut-rate per minute followed a similar trend with Precision discs cutting faster over the duration of the test. With a faster cut-rate, the operator using the disc can finish the job faster than when using Norton or Sia discs.

Product Solution Selector

3M offers several families of Scotch-Brite™ Surface Conditioning Discs with different properties (flexibility, durability, aggressiveness, etc.) made for various customer applications. A clear method of delivering product recommendations to the customer is needed. An interactive solution selector was created using an algorithm for comparing various Scotch-Brite™ product families and proposing the right nonwoven disc for a given job. A corresponding tool and accessories selector algorithm and interface were also created.

First, a surface conditioning disc recommendation algorithm was created. Nine surface conditioning product families were considered for selection: Scotch-Brite™ LGB, Scotch-Brite™ SC, Scotch-Brite™ SE, Scotch-Brite™ SL, Scotch-Brite™ Deburr and Finish Pro, Scotch-Brite™ Clean and Strip, Scotch-Brite™ Blend and Finish, 3M™ Cubitron™ II 775L, and Scotch-Brite™ Precision. Each family also consists of up to 6 grades which impart varying surface finishes on a substrate. A selection algorithm prioritized 3M products based on 1) surface finish imparted, 2) disc flexibility, and 3) product life with alignment of these disc properties with typical needs for a specific job or substrate geometry. For example, when a user selects a flat substrate with no other constraints, they would be recommended Scotch-Brite™ Precision Surface Conditioning Discs based on the product life, while Scotch-Brite™ SC would be recommended by the algorithm if the user selected extra product flexibility in addition, based on the data provided in **Figure 5, Figure 6 and Figure 11**. Also, based on aggregated feedback from customer testing, the product solution selector includes disc recommendations for industry specific tasks, e.g., micro-burr removal. Second, a selection guide to

accessories and power tools was generated using an algorithm to display available products based on the user's preferred disc size and/or tool threading. The solution selector uses these parameters to narrow down >1,000 3M tools and accessories SKUs to a few relevant product recommendations.

CONCLUSION

Nonwoven abrasives discs have been growing in popularity globally and are known for their flexibility and ability to finish surfaces without creating major damage to the substrates. The Scotch-Brite™ Precision Surface Conditioning Disc design offers longer life and a faster cut than current surface conditioning discs and the product design leverages multiple new technologies which brings value to customers who seek improved productivity, quality, ergonomics and safety.

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Author Contributions
The manuscript was written through contributions of all authors. / All authors have given approval to the final version of the manuscript.

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Abbreviations
PSG, 3M Precision-Shaped Grain; SS, stainless steel; CS, carbon steel

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[4]3M uses a plus (+) for the grading of Precision-Shaped Grain. The physical dimensions of PSG are larger grade for grade compared with crushed mineral using the ANSI, FEPA, of JIS standards.
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