A Close Shave — New PFAS Free Alternatives to PTFE Surface Lubricating Coatings for Razor Blades Could Mean Great Shaving and A Better Environment

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Abstract

Per- and polyfluoroalkyl substance ("PFAS") are a class of compounds containing carbon-fluorine bonds that can impart unique properties to materials and surfaces. However they are very long-lived in the environment, and there is evidence that they are harmful to human health. While the use of these materials enables technologies across many industries, upcoming restrictive legislation surrounding perfluorinated substances is being proposed to limit the use of these materials only when they are deemed essential. One application is the use of PFAS coatings as lubricants for cutting edges, such those used in consumer razors. In anticipation of restrictions being imposed on this application of PFAS materials, Aculon, Inc. (Aculon) investigated potential fluorine-free alternatives to fluorocarbon-containing coatings on cutting edges used in consumer razors. Potential nonfluorinated coatings that can approach the lubricating effect of poly(tetrafluoroethylene) (PTFE) on razors were explored.

Introduction

Lubricating coatings on razor blades are thin films that reduce friction between the blade and the skin during shaving and reducing the force required to cut hair. Virtually all shaving razor blades have a PTFE lubricating coating on the edges to enhance comfort while shaving. While PTFE coatings on razor blades can provide a smoother and more comfortable shaving experience, it has negative environment impacts because it is not biodegradable and can persist in the environment for a long time. PFAS compounds are a byproduct of the production of PTFE and can also be used in formulations of PTFE powders to keep them in suspension. PFAS are persistent organic pollutants that can accumulate in living organisms and potentially cause a range of health issues, including liver/kidney damage, cancer, and development of disorders [1-3]. Due to the potential health effects, there have been restrictions on the use of specific PFAS compounds in the past, and new restrictions on the horizon.

For example, perfluorooctanoic acid, “PFOA,” and its salts and related compounds were banned under the POPs Regulation since 4 July 2020 [4]. New restrictions [5] covering a wide range of PFAS were proposed to ECHA in January 2023 by the governments of Denmark, Germany, Netherlands, Sweden, and Norway. It advocates the prohibition of the production, marketing, and use of these substances throughout Europe except in critical applications where there are no acceptable nonfluorinated substitutes (for example, PTFE used in medical devices).

Regulation of PFAS is an ongoing process. The United States Environmental Protection Agency (EPA) in set regulatory limits for PFAS, such as in drinking water, and more and more states have implemented their own regulations, including bans on certain uses of PFAS in consumer products [6,7]. The EPA also announced plans for regulation that would, for the first time, set limits on the level of PFAS that could be discharged in wastewater. During normal use, over 80% of the PTFE coatings on a razor blade wear down and are washed into the municipal wastewater systems where no methods exist to remove PFAS from water. Furthermore, in 1990 the EPA estimated 2 billion disposable razors and blades get tossed out each year in the U.S. alone [8]. Given population growth, that number has grown. Any razors disposed to landfill could eventually leach remaining PFAS on the blades into the water column over time.

Consequently, there is an urgent need to find PFAS-free coating alternatives to reduce the potential environmental and health risks associated with these substances and promote the development of more sustainable and responsible products.

The PTFE lubricating coating was disclosed in 1963 mentioning a decrease in the force required to cut human hair [9]. The coated and uncoated blades were tested under controlled conditions. It was found that there was less tendency for the coated blades to pull resulting in increased ease of shaving. In the past 40 years, other PTFE-alternative coatings were discovered. Numerous reports in the patent literature range from hydrophilic poly (ethylene oxide) all the way to hydrophobic poly (dimethylsiloxane) treatments, but these PTFE-alternative coatings have not had anywhere near the adoption rate compared to PTFE among the major razor blade manufactures [10,11]. This is likely due to PTFE coatings having the greatest combination of friction reduction and durability on the blade edges. Therefore, current lubricating coatings on razor blades still rely on PFAS-containing materials for all the major manufacturers.

A new class of nanoscale surface treatments have arrived based upon supramolecular self-assembly that are very promising candidates for replacing PTFE on cutting edges which can provide good cutting performance and durability while reducing the potential risks to the environment and human health.

Methods and Materials

In view of the current proposed legislature in the European Union (EU), Aculon reevaluated razor blade coatings, given many recent advancements in nanoscale surface chemistry over the last few decades. Several different nanoscale surface treatments were selected over a dozen of Aculon's advanced nanoscale surface treatments and tested using methodology similar to what is used in the razor blade industry [12]. Given that production globally for razor blades runs into the high tens if not hundreds of billions of units annually, any application process designed to replace the current PTFE deposition process must be simple and highly scalable. Treatments were selected that could easily be applied with a simple process.

Conventional stainless steel razor blades with symmetric wedge-shaped cutting edges were used during the evaluation to compare many different surface treatments to the conventional PTFE coatings. Tests of the cutting force of treated blades were conducted in a mechanically controlled condition. A razor blade holder was mechanically attached under a force gauge which was placed perpendicularly to the horizontal platform. The razor blade edge was parallel to a horizontal platform. Felt with 3 mm thickness and 2.5 cm width was used as cutting material and placed underneath the razor blade on the platform [13]. The razor blade was lowered down until it began to cut the felt perpendicularly. The average cutting force required to penetrate/cut the felt was recorded. It is important to define the cutting force that was used to quantify coating quality. Felt is a soft material and there are several stages in the cutting process which is shown in Figure 1. The trend of change in cutting force and displacement during cutting into the felt is shown in

Figure 1. The stiffness (=Force/Displacement) vs. displacement chart illustrates more information about the state of transition.

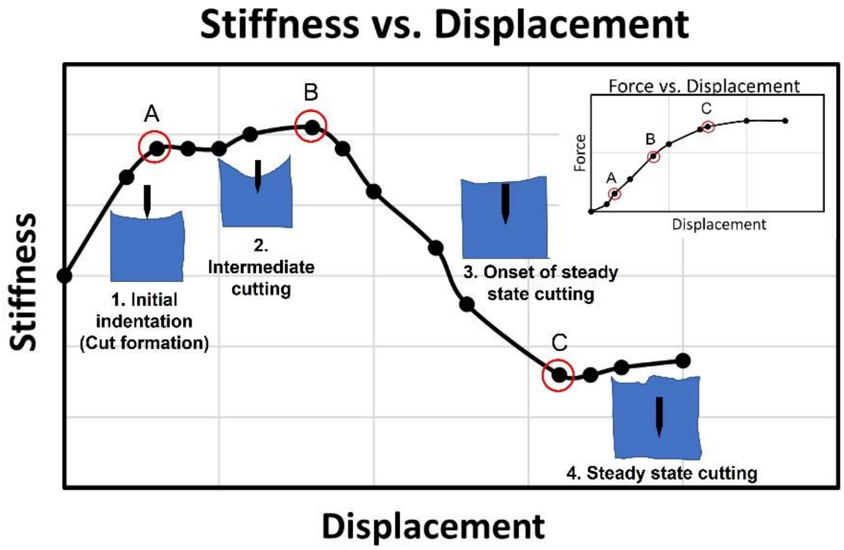

Figure 1. Indentation cutting with razor blade (Stiffness vs. Displacement curve)

The felt deforms to some extent when the blade starts to cut. Up to point A, the initial cut forms. Then from point A to B, part of the blade travels inside the felt. From B to C, the whole blade is in the felt. And from point C, steady state cutting happens.

The cutting force that was measured in the test was at point A when the initial cut started to form. Both dry and wet felt were used to measure the cutting force of different treated razor blades. Wet felt was prepared by soaking the dry felt in DI H_2O for 20 min. Ten cuts were performed in each test to demonstrate durability. Each type of coating was tested three times. Over a dozen different supramolecular coating systems developed by Aculon were tested, including PFAS-containing options and PFAS-free options to compare the effects of fluorocarbon content. The initial tests help downselect potential candidates to a smaller field. Uncoated as control, PTFE coating, Aculon "Fluorocarbon", Aculon "Non-PFAS1" and Aculon "Non-PFAS2-1 to -4". The results of both dry and wet felt cutting tests are shown in Figure 2. The top three coatings from Aculon, together with uncoated and PTFE coated results, are presented in Figure 3. The average force of 10 cuts of each type of treatment is summarized in Figure 4.

All the treatments show high durability within 10 cuts in both dry and wet felt tests. The PTFE-coated blades display the lowest average cutting force among all the others. The alternative coatings tested demonstrate significant reductions (more than 50%) in cutting force compared to control (uncoated) and are quite close to the performance of PTFE in both dry and wet felt tests. The slight difference in the felt cutting tests may not be enough to be differentiate in human tactile trails, so it is suggested that future investigations be run with randomized blind shaving trials with human participants.

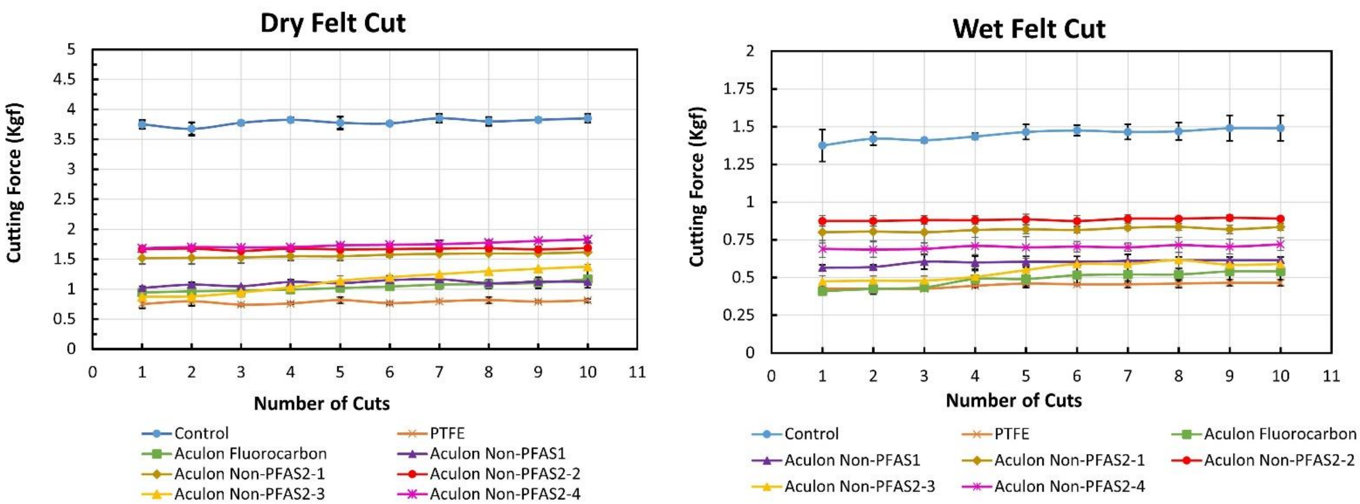

Figure 2. The cutting force of uncoated and different surface treated razor blades were tested on dry and wet felt.

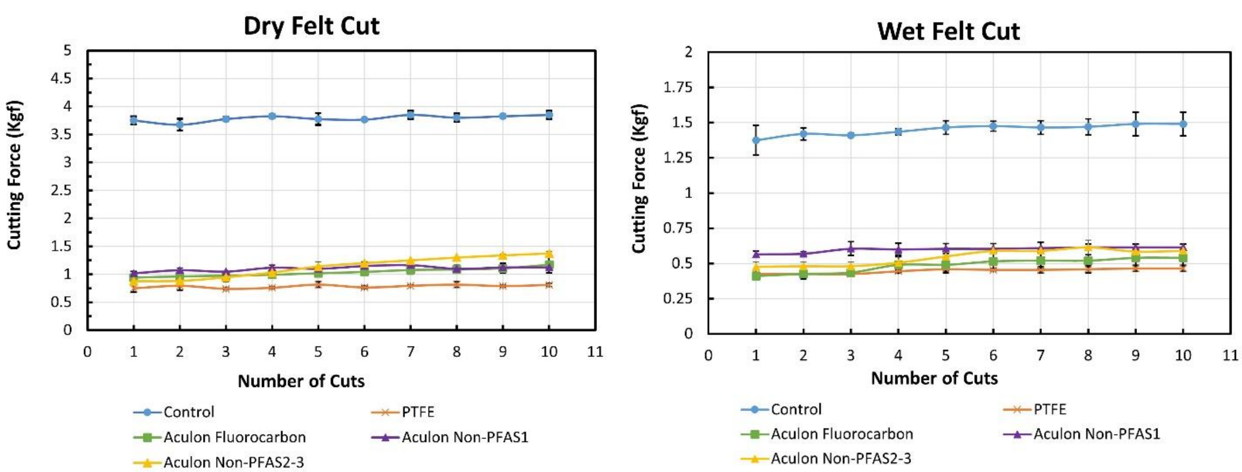

Figure 3. The cutting force of uncoated and PTFE and top 3 Aculon's coated razor blades were tested on dry and wet felt.

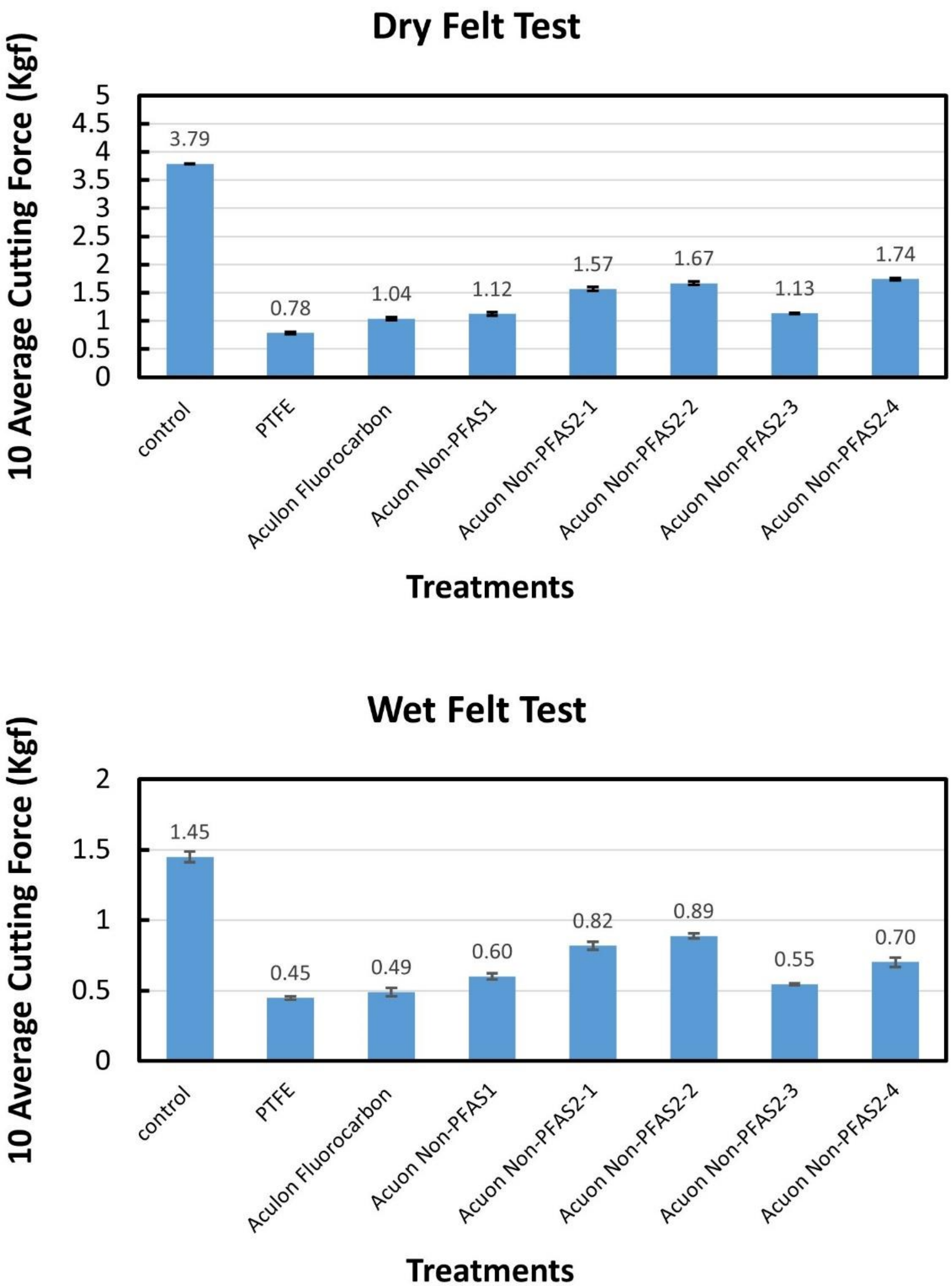

Figure 4. 10 average cutting force of uncoated and different surface treated razor blades tested on dry and wet felt.

Conclusions

The Aculon tests indicate that there are potential PFAS-free alternatives available to PTFE for improving lubrication and reducing friction of razor blades. The surface treatments tested in this research displayed performance levels very close to industry-standard PTFE coatings in both dry and wet tests. With further optimization and testing with humans, there will be successful in finding PFAS-free alternatives that meet the consumer's and can be produced at very high volume with a simple process.

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