Chemically Resistant Polymers for Next Generation Devices

Preventing environmental stress cracking in consumer and healthcare applications

INTRODUCTION

Recent epidemics and pandemics such as SARS, Ebola, and COVID-19 have highlighted the importance of cleaning and disinfection for reducing disease transmission in our highly interconnected world. The frequency of disinfectant usage is particularly high in public establishments, places of work, and healthcare environments. For hospitals and other healthcare facilities, infection prevention is critical for improving patient outcomes by reducing the incidence of healthcare-associated infections (HAIs). HAIs constitute a significant burden (approximately 28-45 billion USD) to the U.S. healthcare system and affect 1.7 million patients annually.[1,2] However, heavy chemical exposure to devices and other equipment that often contain various plastic components poses an additional challenge—many of the materials being used today are not designed to withstand such routine cleaning or the wide variety of disinfectants employed. Often times, this “new normal” of disinfection can lead to material failure through a phenomenon called environmental stress cracking (ESC).

ESC can be defined as the premature embrittlement and crack propagation of a material caused by the synergistic action of stress and chemical exposure. Accounting for 25% or more of observed failures in the field, it is believed that ESC is the leading cause of plastic component failure.[3] To better understand the environmental contribution of stress cracking, it is helpful to examine stress cracking in air (creep). When a material is exposed to sufficient mechanical stresses in the absence of chemical exposure, particularly stresses below the level which would normally cause permanent deformation (i.e., the yield point), it will demonstrate creep behavior. Over time, individual polymer chains can rotate, slide, and align in response to the applied stress, leaving behind micro-voids of previously occupied space. These voids eventually grow larger with aligned polymer fibrils extending between them (Figure 1), which manifests as a series of fine cracks or “crazes” in a planar array normal to the stress.[4,5] The crazes continue to propagate and eventually rupture, leading to cracking and further stress concentration that inevitably causes brittle failure. Interestingly, ESC and creep exhibit parallel failure mechanisms, however, the addition of chemical exposure can greatly accelerate the timeline to component failure. When a chemical stress cracking agent diffuses into a polymer network it can increase the chain mobility and free volume of the system. This change reduces the critical strain required for stress cracking and expedites the previously described failure mechanism.

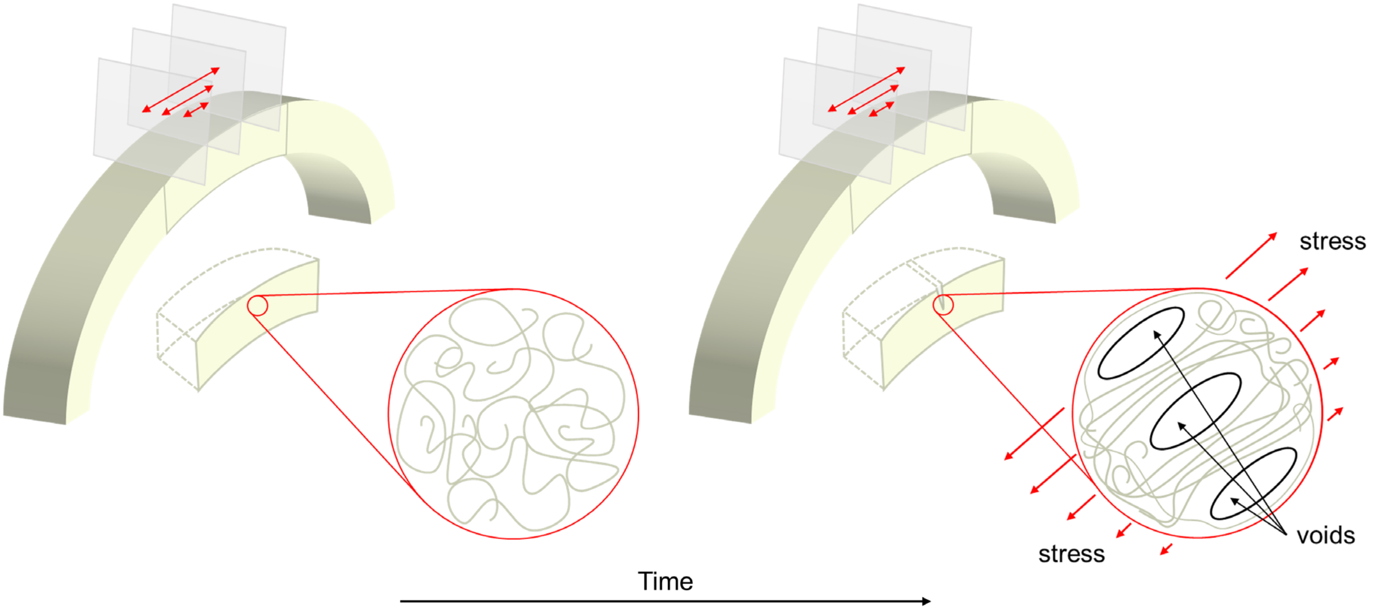

Figure 1. Schematic representation of creep mechanism; chain alignment and void formation in response to applied stress.

There are several key factors which can influence the timeline to ESC failure:

1. Frequency of exposure to a stress cracking agent (i.e., cleaner or disinfectant)
2. Solubility parameters of the polymer and stress cracking agent
3. Magnitude of residual/applied stress in the component

While it is intuitive that higher temperatures and higher applied stress can expedite creep behavior and stress cracking, chemical exposure can be more obscure and inconsistent. Generally speaking, the more frequently a part is exposed to a stress cracking agent, the more opportunities the agent has to penetrate or diffuse into the polymer network and cause damage. In some instances, a single exposure to a strong stress cracking agent may cause premature failure, yet in others it may appear to have no effect after numerous applications. This can be primarily attributed to differences in the solubility parameters of the primary solvent/stress cracking agent and the polymer itself. It has been demonstrated in literature that the critical strain required for stress cracking is at a minimum when the difference between the solubility parameters of the polymer and stress cracking agent are minimized. Although, it has been observed that swelling non-solvents (theta solvents) are the most potent stress cracking agents, since solvation of the polymer with good solvents may result in gelation or crystallization at the exposure site and prevent stress cracking.[4] Lastly, higher residual or applied stresses imparted to the plastic component can also expedite the time to stress cracking failure. Processing parameters and part design can influence the residual stresses in a part; higher melt and mold temperatures with longer cooling times can reduce residual stress during molding, whereas coring features, bosses, and round/oval holes (when necessary) can help alleviate internal stresses around part corners.

In this study, Avient's Trilliant™ HC8900 and Edgetek™ ET8900 thermoplastics were tested alongside competitive materials used for various medical and consumer device enclosures. The materials were evaluated for environmental stress cracking resistance (ESCR) using an adaptation to ASTM D543 "Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents." This study included exposing the materials to leading medical-grade disinfectants, as well as common household disinfectants/cleaners.

MATERIALS AND METHODS

The following commercially available healthcare disinfectants were utilized for ESCR testing: CaviCide™, Super Sani-Cloth®, SporGon™, Vesphere® IIse, and Virex® TB. In addition, the common household disinfectants investigated were Clorox® Disinfecting Wipes, Formula 409® Heavy Duty Degreaser, and Lysol® All-Purpose Cleaner. Table 1 shows a summary of the disinfectants and key features, such as the EPA registration number and relevant ingredients.

Table 1. List of disinfectant/cleaners and corresponding details.

DISINFECTANT/CLEANER	EPA REG. NO.	ACTIVE INGREDIENT	RELEVANT INGREDIENTS
CaviCide™	46781-6	Quaternary Ammonium	Isopropanol 2-Butoxyethanol
Super Sani-Cloth®	9480-4	Quaternary Ammonium	Isopropanol
SporGon™	N/A	Hydrogen Peroxide Peracetic Acid	N/A
Vesphene® IIse	1043-87	2-Phenylphenol 4-Tert-Amylphenol	Potassium Hydroxide Sodium Hydroxide
Virex® TB	70627-2	Quaternary Ammonium	Diethylene Glycol Butyl Ether
Clorox® Disinfecting Wipes	5813-79	Quaternary Ammonium	Hexoxyethanol Isopropanol Ethoxylated Alcohols
Lysol® All-Purpose Cleaner	67619-10	Quaternary Ammonium	1-Phenoxy-2-Propanol Ethanolamine Dipropylene Glycol
Formula 409® Heavy Duty Degreaser	N/A	N/A	Propylene Glycol Butyl Ether Ethanolamine

CaviCide™ is a trademark of Metrex Research, LLC; Sani-Cloth® is a trademark of Professional Disposables International, Inc.; SporGon™ is a trademark of Decon Labs, Inc.; Vesphene® is a trademark of Steris Corporation; and Virex® is a trademark of Diversey, Inc.; Lysol® is a trademark of Reckitt Benckiser LLC; Formula 409® is a trademark of The Clorox Company; Clorox® is a trademark of The Clorox Company.

For the materials tested, a variety of flame-retardant (FR) polycarbonate (PC) alloys, including blends with acrylonitrile-butadiene-styrene (ABS), polyethylene terephthalate (PET), and polybutylene terephthalate (PBT), were benchmarked against FR copolyester and the chemically resistant (CR) aliphatic polyketone (PK) blends of the Trilliant HC8900 and Edgetek ET8900 series. The PK blends included unfilled, high impact (HI), and FR grades. Identifying features of the various materials used in this study are summarized below in Table 2.

Table 2. List of polymers tested and identifying features.

MATERIAL	BRIEF DESCRIPTION
FR PC/ABS	Flame retardant, chemical resistance, high ESCR
FR PC/PET	Flame retardant, impact modified, chemical resistant
FR PC/PBT	Skin-contact biocompatible, flame retardant, high chemical resistance
FR Copolyester	Flame retardant, chemical resistant, may incorporate agency-rated materials to meet USP Class VI or ISO 10993 requirements
Trilliant™ HC8910	Unfilled PK blend, BPA-free, high chemical resistance, may incorporate agency-rated materials to meet USP Class VI or ISO 10993 requirements
Trilliant™ HC8920 FR	Non-halogenated flame retardant PK blend, BPA-free, high chemical resistance, may incorporate agency rated materials to meet USP Class VI or ISO 10993 requirements
Edgetek™ ET8900 CR	Unfilled PK blend, high chemical resistance
Edgetek™ ET8900 HI CR	High impact PK blend, high chemical resistance
Edgetek™ ET8920 FR CR	Non-halogenated flame retardant PK blend, high chemical resistance

In order to benchmark the relative ESCR performance of the materials tested, an adaptation to the ASTM D543 method was used. Briefly, ASTM D638 Type I tensile bars were prepared for each material by injection molding using a 2-stage setup procedure, applying a hold pressure of 60% of the injection pressure once a 98% full part was achieved. All materials were pre-dried and molded to the specifications provided by the manufacturer. After molding, the bars were allowed to condition for at least 48 hours under standard lab conditions (23°C, 50% RH), and were then placed into a fixed-strain apparatus (Figure 2) with a nominal flexural strain of 1.0%. For the control group, the tensile bars were positioned in the strain tool and left untreated for 72 hours. For treatment groups, a 0.5" (13 mm) square pre-soaked gauze pad containing the disinfectant/cleaner of choice was applied to the center portion of the test specimen, replacing the gauze pad every 24 hours for a total of 72 hours (3 applications). Following the treatment period, the tensile bars for the control and treatment groups were tested within 48 hours using the ASTM D638 method at a rate of 2 in/min (50.8 mm/min), and the percent retention of tensile properties were determined relative to the respective control.

To assess the results of the chemical resistance testing, an ESCR criteria was developed that took into consideration a visual observation as well as the mechanical data. For visual observation, if the sample survived the strain tool and chemical exposure without brittle failure then a positive mark was granted. In addition to surviving the treatment period, if the sample did not exhibit signs of significant crazing or cracking then an additional positive mark was granted. Regarding tensile properties, three additional categories granted positive marks:

1. Tensile strength and elongation at yield retention between 75-125%
2. Tensile strength and elongation at yield retention between 90-110%
3. No statistically significant reduction in elongation at break ($p < 0.05$)

The overall rating was based on an additive scale with each criteria treated independently, thus it was possible to have significant crazing yet acquire positive marks for retaining tensile properties (or vice versa).

RESULTS AND DISCUSSION

For demonstration, the tensile results for the adapted ASTM D543 testing with Virex® TB are shown in Figure 2, as well as the corresponding images of tensile bars in the strain apparatus following the 72-hour treatment period. It can be seen that the PC/ABS and PC/PET samples failed to survive the disinfectant exposure and produce a testable sample. The FR copolyester did not exhibit obvious signs of crazing, but the tensile strength and elongation at yield were notably reduced along with a significant reduction in tensile elongation at break ($p < 0.05$). The Trilliant HC8910 and HC8920 materials were apparently unaffected by the application of Virex® TB and demonstrated nearly 100% retention of tensile properties relative to the strain control group. In addition to Virex® TB, seven other disinfectants common to the healthcare and consumer industry were tested and the results were recorded in Table 3.

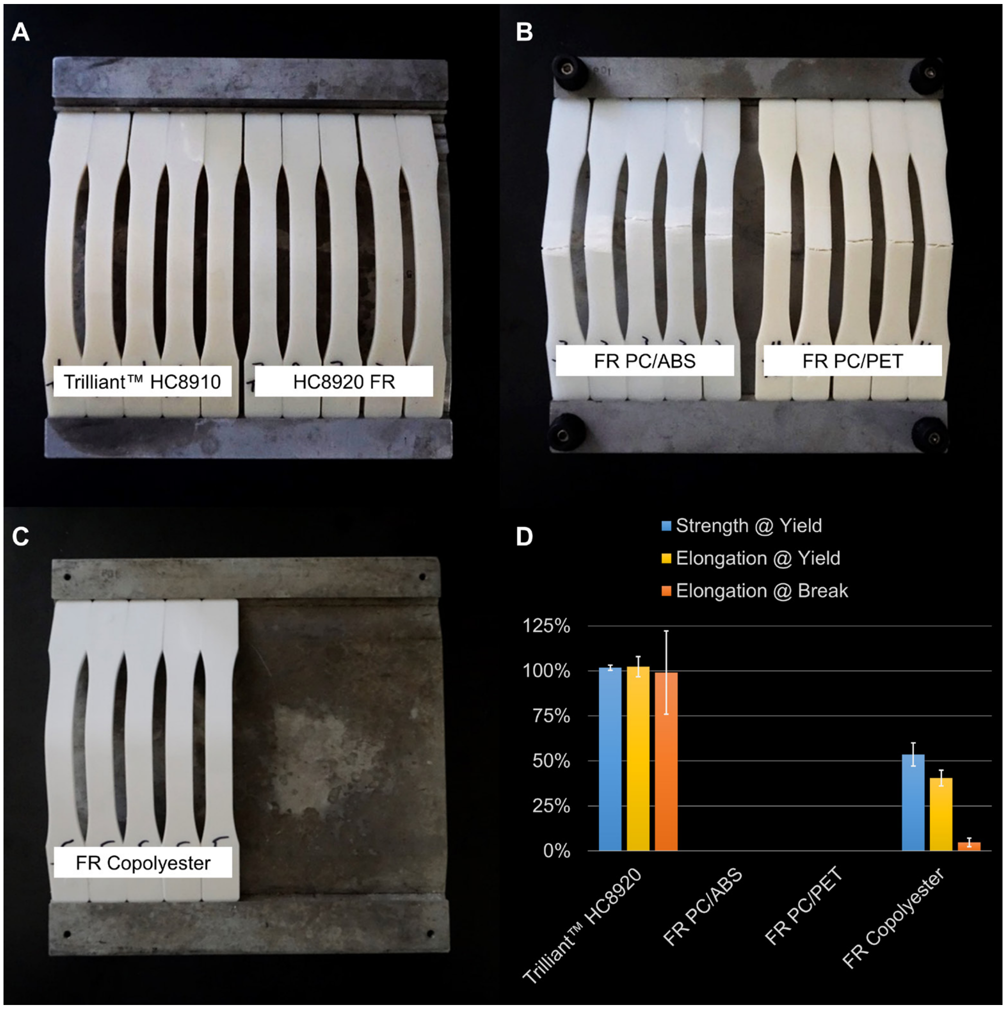

Figure 2. Adapted ASTM D543 testing with Virex® TB. Images of A) Trilliant HC8900 series, B) FR PC alloys, and C) FR copolyester tensile bars in the strain apparatus following a 72-hour treatment with Virex® TB. D) Corresponding tensile data showing property retention for treatment groups relative to their respective controls.

The combination of visual observation and mechanical properties afforded an ESCR rating as described previously, which is summarized in Table 3A for healthcare disinfectants and Table 3B for common household/consumer disinfectants tested in this study. The data in these tables clearly shows that the Trilliant HC8900 and Edgetek ET8900 series outperformed the competitive materials across all different disinfectant/cleaner types. The Trilliant HC8900 and Edgetek ET8900 series are polymer blends based on linear aliphatic PK. Their outstanding chemical resistance can be attributed to the crystallinity and limited solubility of PK. Furthermore, synergistic PK blends can enhance their resistance to aqueous solutions, even in the presence of surfactants and co-solvents such as those used in disinfectant/cleaner mixtures. Second to the Trilliant series, the FR copolyester demonstrated good ESCR performance, but struggled against more aggressive disinfectants (e.g., Virex® TB). Due to the higher cost position of copolyester, it was substituted for PC/PBT in the consumer disinfectant testing. With regards to PC alloys, the general trend of increasing chemical resistance was observed in order of PC/ABS < PC/PET < PC/PBT, which was expected based on previous research and the marketing literature of PC blend manufacturers.[4] However, the Edgetek ET8900 series clearly demonstrated the best ESCR performance against the household cleaners.

Table 3A. Resistance ratings for Trilliant HC8900 series and competing materials against common healthcare disinfectants.

CRITERIA FOR RESISTANCE RATING

+ yield point retention between 90-110%
+ yield point retention between 75-125%
+ no significant reduction in elongation
+ minor/no crazing, no cracking
+ survived 72 hour exposure in strain jig

	Trilliant™ HC8910	Trilliant™ HC8920 FR	FR PC/ABS	FR PC/PET	FR Copolyester
DISINFECTANT	**RESISTANCE RATING**				
CaviCide™	+++++	+++++	+++	++++	+++++
Super Sani-Cloth®	+++++	+++++	+++++	+++++	+++++
SporGon™	+++++	+++++	++++	++++	++++
Vesphene® IIse	+++++	+++++	-	++	++++
Virex® Tb	+++++	+++++	-	-	++

Table 3B. Resistance ratings for Edgetek ET8900 series and competing materials against common household cleaners and disinfectants.

CRITERIA FOR RESISTANCE RATING

+ yield point retention between 90-110%
+ yield point retention between 75-125%
+ no significant reduction in elongation
+ minor/no crazing, no cracking
+ survived 72 hour exposure in strain jig

	Edgetek™ ET8900 CR	Edgetek™ ET8900 HI CR	Edgetek™ ET8920 FR CR	FR PC/ABS	FR PC/PET	FR PC/PBT
DISINFECTANT/CLEANER	**RESISTANCE RATING**					
Clorox® Disinfecting Wipes	+++++	+++++	+++++	++	+++	++++
Formula 409® Heavy Duty Degreaser	+++++	+++++	+++++	+	++	+++
Lysol® All-Purpose Cleaner	+++++	+++++	+++++	+	+	++

CONCLUSION

In summary, a series of polymers including various PC alloys and a copolyester were tested in parallel to the Trilliant HC8900 and Edgetek ET8900 series against eight common healthcare and consumer disinfectants/cleaners. The study suggests that overall, the Trilliant and Edgetek PK blends have enhanced ESCR performance against a variety of disinfectants/cleaners compared to competitive materials available in the market. While the method used in this study is useful for providing comparative data, it should be noted that the testing is conducted under a single strain condition with the disinfectant applied in a manner intended to accelerate ESC behavior; the strain and exposure conditions based on actual use scenarios should always be tested to confirm the anticipated performance in the field.

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