Damage to Common Healthcare Polymer Surfaces from UV-C Exposure

Authors: Peter Teska[1], Roderick Dayton[1], Dr. Xiaobao Li[1], Jason Lamb[1], Phillip Strader[2]
[1] Diversey Inc, Fort Mill SC, [2] North Carolina State University, Raleigh NC

Introduction:

Healthcare associated infections are a significant concern in acute care facilities across the US[1]. Studies have shown the importance of a hygienic patient environment in reducing the risk of such infections[2,3]. This has caused an increased interest in ultraviolet light disinfectant technology as an adjunct technology to provide additional pathogen reduction to environmental surfaces and patient care equipment (i.e. surfaces)[4-6]. It is also well known that ultraviolet light (UV-C) can cause premature degradation of materials, particularly certain plastic materials[7-11].

However, there is little information in the literature regarding characterizing this degradation of plastics and other materials used for surfaces in healthcare. This study evaluated multiple characterization techniques discussed previously[12-13] and proposes a systematic approach to further understand early onset degradation of plastics due to UV-C exposure.

Materials and Methods:

Ten grades of plastic materials were exposed to UV-C light in a manner consistent with standards given in the healthcare and furniture industry to achieve disinfection. Approximately 1 inch x 2 inch samples of ten types of polymers were cut from larger sheets of the material using a laser cutter. All samples were convenience samples cut from larger sheets purchased from McMaster-Carr, a commercial materials supplier. The materials included:

- Polypropylene (PP)
- Ultra High Molecular Weight Polyethylene (UHMW PE)
- Polytetrafluoroethylene (PFTE or Teflon)
- Clear polymethyl methacrylate (PMMA or clear acrylic)
- White polymethyl methacrylate (PMMA or white acrylic)
- Polyoxymethylene (Delrin)
- Polyester (poly[ethylene terephthalate] or PET)
- Polycarbonate
- Nylon
- Acrylonitrile butadiene styrene (ABS)

Each sample was exposed to 6 hours 24 minutes of UV-C energy at the distance of 1 meter from a low pressure, high output soft glass mercury-vapor UV-C bulb. The exposure time was determined by calculation based on the BIFMA standard [14]. According to BIFMA standard[14], the total UV-C energy exposure for each test period should be:

(500 µW/cm2)/sec X 60 sec/min X 60 min/hr X 16 hr/test period X 1x10-6 J/µW = 28.8 J/cm2

These materials were characterized by:

- Visual appearance using confocal laser scanning microscopy (CLSM)
- Chemical composition change using Fourier Transform Infrared Spectroscopy (FTIR)
- Surface energy using water contact angle via goniometer
- Surface roughness/profilometry using CLSM
- Material hardness using nanoindentation

Results:

Table 1: Mean change in water contact angle (+/-SD) to select plastics after exposure to UV energy.

Sample	Untreated (deg)	UV Exposed (deg)	% Change	P-Value
ABS	87.0 ± 7.2	61.7 ± 3.1	-29.0	<0.001
White acrylic	62.4 ± 7.4	70.3 ± 8.6	12.7	0.116
Clear acrylic	82.4 ± 4.9	52.9 ± 6.9	-35.8	<0.001
Delrin	80.9 ± 4.3	73.2 ± 3.2	-9.7	0.0048
Nylon	89.0 ± 1.5	62.7 ± 5.9	-29.6	<0.001
PC	88.0 ± 3.4	66.3 ± 5.5	-24.7	<0.001
PET	138.1 ± 3.0	81.3 ± 3.5	-41.1	<0.001
PP	86.6 ± 5.4	82.7 ± 1.8	-4.5	0.124
Teflon	113.9 ± 5.9	101.6 ± 3.6	-10.8	0.0015
UHMW	90.6 ± 6.0	84.0 ± 3.4	-7.3	0.0413

Table 2: Change in Root Mean Square (Sq) surface roughness (+/- SD) in select plastics after UV exposure.

Sample	Untreated Sq (µm)	UV Exposed Sq (µm)	Change (%)	P-Value
ABS	1.54 ± 0.26	1.81 ± 0.33	17.5	0.0703
White acrylic	1.22 ± 0.12	1.67 ± 0.92	36.9	0.1733
Clear acrylic	0.96 ± 0.21	0.89 ± 0.16	-7.3	0.4602
Delrin	1.78 ± 0.18	2.06 ± 0.15	15.7	0.0017
Nylon	1.59 ± 0.27	2.33 ± 1.71	46.5	0.2146
PC	1.08 ±0.07	1.28 ± 0.24	18.5	0.0276
PET	7.77 ± 0.70	6.90 ± 0.39	-11.2	0.0045
PP	2.02 ± 0.16	1.84 ± 0.24	-8.9	0.0751
Teflon	4.54 ±0.27	4.87 ± 0.67	7.3	0.1955
UHMW	3.89 ± 0.35	4.90 ± 0.95	25.9	0.0077

Table 3: Change in color for select plastics after exposure to UV energy.

Sample	L*a*b, Δ E Value	ASTM Whiteness, % Change
ABS	3.28	-12.23
White acrylic	10.66	-48.83
Clear acrylic	0.12	-0.49
Delrin	1.54	-7.10
Nylon	2.67	-9.45
PC	3.89	-17.52
PET	1.15	-5.82
PP	0.12	-0.51
Teflon	0.66	-3.37
UHMW	0.74	-3.04

Table 4: Change in material hardness (+/-SD) measured through nanoindentation before and after exposure to UV energy.

Sample	Untreated (Mpa)	Treated (Mpa)	Change (Mpa)	P-Value
ABS	265.2 ± 4.6	362.4 ± 6.9	97.2	<0.001
White acrylic	391.9 ± 10.0	374.9 ± 12.4	-17.0	0.0014
Clear acrylic	373.6 ± 2.5	351.4 ± 1.7	-22.2	<0.001
Delrin	395.3 ± 9.9	381.1 ± 12.8	-14.2	0.0061
Nylon	252.4 ± 7.1	253.3 ± 8.2	0.9	0.7737
PC	306.1 ± 6.1	323.7 ± 4.7	17.6	<0.001
PET	251.2 ± 18.5	218.1 ± 16.5	-33.1	0.0003
PP	223.2 ± 1.71	199.6 ± 1.51	-23.6	<0.001
Teflon	274.0 ± 50.7	226.6 ± 15.1	-17.3	0.0057
UHMW	204.4 ± 4.6	197.3 ± 0.3	-7.1	<0.001

Discussion and Conclusions:

The primary implication of the study is that while it is important to apply an adequate level of UV-C energy to achieve efficacy, it is equally important not to apply excess UV-C energy as it can accelerate surface damage and prematurely shorten the useful life of the asset. All characterization methods were able to identify one or more specific degradation features from UV-C exposure covering different aspects of physicochemical properties of the surfaces. However, these methods showed different sensitivity and applicability to identify the onset of surface damage. Different types of surface materials showed different susceptibility and modes to degradation upon UV-C exposure.

Materials such as ultrahigh molecular weight polyethylene consistently showed little damage except when characterized by profilometry/surface roughness, which showed a significant change ($P<0.01$). Other plastics, such as ABS, consistently showed evidence of increased damage from most test methods, with the exception of optical microscopy, which was not particularly revealing for ABS.

All of these samples showed lesser/minimal damage in at least one characterization method, demonstrating that multiple characterization methods are much more revealing than a single method. The plastics least damaged by UV-C energy were polypropylene and ultrahigh molecular weight polyethylene. The most damaged plastics were white acrylic, ABS, nylon, and polycarbonate, which showed evidence of significant surface damage in multiple characterization methods. These four materials represent the highest risk of damage from excess UV-C exposure, and because these are materials commonly found in the healthcare environment, efforts should be made to limit their exposure to excess UV-C energy, balancing dose with desired efficacy.

References:

1. Magill SS, Edwards JR, Bamberg W, et al. “Multistate Point-Prevalence Survey of Health Care–Associated Infections”. *The New England Journal of Medicine.* 2014; 370(13): 1198-1208. doi:10.1056/NEJMoa1306801.
2. Cohen B, Liu J, Cohen AR, Larson E. “Association between healthcare-associated infection and exposure to hospital roommates and previous bed occupants with the same organism”. *Infect Cont and Hosp Epidemiol.* 2018; 39 (5): 541-546.
3. Otter, et al, “Evidence that contaminated surfaces contribute to the transmission of hospital pathogens and an overview of strategies to address contaminated surfaces in hospital settings”, *Am J Infect Control,* 2013; 41: S6-S11.
4. Boyce JM, Havill NL, Moore BA. “Terminal decontamination of patient rooms using an automated mobile UV light unit”, *Infect Cont and Hosp Epidemiol,* 2011; 32 (8): 737-742.
5. Anderson DJ, Gergen MF, Smathers E, Sexton DJ, Chen LF, Weber DJ, Rutala WA. “Decontamination of targeted pathogens from patient rooms using an automated ultraviolet-C emitting device”, *Infect Cont and Hosp Epidemiol,* 2013; 34 (5): 466-471.
6. Mahida N, Vaughan N, Boswell T. “First UK evaluation of an automated ultraviolet-C room decontamination unit (Tru-D)”, *J of Hosp Infect,* 2013; 84: 332-335.
7. Yousif E, Haddad R. Photodegradation and photostabilization of polymers, especially polystyrene: review. *SpringerPlus,* 2013; 2: 398.
8. Lambert S, Wagner M. Characterization of nanoplastics during degradation of polystyrene. *Chemosphere,* 2016; 145: 265-268.
9. Guzel, A. (2009). *Photo-oxidative degradation of ABS copolymer* (M.S.). Middle East Technical University.
10. Akbay IK, Ozdemir T. “Monomer migration and degradation of polycarbonate via UV-C irradiation within aquatic and atmospheric environments”, *Journal of Macromolecular Science, Part A,* 2016; 53 (6): 340-345.
11. U.S. Department of Commerce. (1978). *Studies on the Photodegradation of Poly(Methyl Methacrylate).* Washington, DC.
12. Jo H, West AM, Teska PJ, Oliver HF, Howarter JA. “Assessment of early onset surface damage from accelerated disinfection protocol”. *Antimicrobial Resistance and Infection Control,* 2019; 8:24.
13. Strader P, Lee Y, Teska P, Li X, Jones J. Approaches for characterizing surfaces damaged by disinfection in healthcare. Nano LIFE, July 2019; doi: https://doi.org/10.1142/S1793984419500028.
14. Business and Institutional Furniture Manufacturer’s Association. Health care furniture design – guidelines for cleanability BIFMA HCF 8.1-2014. 2014. Retrieved from: https://cdn.ymaws.com/www.bifma.org/resource/resmgr/standards/BIFMA_CleanGuide_6Oct14.pdf