The effect of UV-C radiation on the durability of 3D printed plastic parts in disinfectant devices

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Abstract. The usage of far or hard ultraviolet radiation in wavelength 200 – 280 nm or shortly UV-C disinfectors are becoming more and more popular due to their universal ability to fight against bacteria and viruses. It is well known that according to DIN 5031-7, both UV-A and UV-B radiation from sunlight have clear influence on the mechanical and visual properties of plastic parts, but the influence of intensive artificial UV-C is not so widely investigated. As the UV-C is in the shorter end of the UV radiation wavelength spectrum and is completely absorbed by the ozone layer and atmosphere, it is not possible to see the influence of it in everyday life. But in the equipment where the artificial UV-C radiation wavelength is used as a disinfectant, and probably in the open space, the influence of UV-C could be remarkable. Recently, there has been increasing interest in the food industry to avoid contamination in the food packing process. The global COVID-19 coronavirus pandemic has amplified this interest and has forced authors to run a set of tests with printed plastic parts. This paper analyses the outcome of those tests including two different printing directions and two different surface paints. The study shows that there is considerable influence of UV-C radiation on mechanical and aesthetic properties of 3D SLS printed PA12 parts. However, the influence can be diminished by use of appropriate paints.

1. Introduction
3D printing has made continuous growth already throughout many decades [1]. The need for high quality printed parts is still growing and many different areas of use have been implemented, as printed parts are used in final products, not just prototypes. In the era of the COVID-19 pandemic, UV-C disinfection devices have become increasingly popular. However, if 3D printing is also increasingly used in UV-C disinfection devices, new challenges are faced. Different parts like lamp holders, filter housings, shutters etc. can be made of polymers printed with different 3D printing technologies. Studies show that for equivalent incident dosages, UV-C degrades human stratum corneum (the most superficial skin layer) the most [2], so those devices are classified as sources of danger regarding ISO 15858:2016. Therefore, designers of the devices should pay attention and follow all mechanical properties of those parts and materials. And one should follow it during the whole lifecycle of the device, even if the parts are used in prototype making stage. It is understandable that inside the sterilization device near the UV radiation source UV-C radiation level can be very high. As the authors of the current paper are involved in UV-C disinfection cabinet design group the question arose how much we can trust those printed parts in critical places. As first 8 hours in small and light UV-C cabinet did change remarkable the color of high-quality 3D SLS printed part reasonable suspicion occurred, that mechanical properties of printed parts may change as well.

First, main topic of current paper is 3D printing as production method. Two most popular 3D printing technologies are introduced and compared here shortly. We should consider that models for mock-ups
and product visualization purpose only are made with simplest printing solutions like Fused Filament Fabrication (FFF)/Fused Deposition Modeling (FDM). Mechanical properties of FFF technology are weak and surface quality is poor. On the other hand, printing device itself has significantly lower cost and it has a way smaller size as well. Another positive side of FFF/FDM printing technology is that different colors can be combined in order to create colorful parts. The method also uses an exact amount of plastic filament required for the needed detail, meanwhile in Selective Laser Sintering (SLS) methods where plastic powder waste amount is larger. [3] But if we compare from the component quality side then all parameters are better in case of SLS technology. To avoid the temptation to use only FFF printing the Plastic Selective Laser Sintering (PSLS) printing method as a more exact, finer, and more suitable for UV device parts, should be deeply investigated. In current tests only SLS method is used for specimen printing.

Second topic of current paper is UV radiation and its feature to influence polymers. Most polymer parts tend to be affected by UV rays (100…400 nm range of electromagnetic wave), and after a certain time it is noticeable that their surface becomes chalky, brittle and its color changes.

In terms of the components more likely to be at risk of UV damage, all outside parts are endangered. As it was mentioned before, a change of the material’s surface layer takes place. But in some cases, if the object is damaged by UV, it may also cause complete component breakage.

If we look more deeply into UV types, one can acknowledge that based on the most investigated material—skin—UV-A (wavelengths 320 to 400 nm) causes aging and tanning of the complexion, while UV-B (wavelengths 280 to 320 nm) may mean it burns. The common effect of UV-C (wavelengths 200 to 280 nm) is germicidal, which kills or inactivates microorganisms by destroying nucleic acids and disrupts their DNA [4].

Our hypothesis is that if we can prove that UV-C influence on mechanical properties of SLS printed parts (with or without paint layer) is not remarkable then those parts have the advantage of working properly and lasting the whole lifecycle of the UV device.

A lot of different research has been carried out with different UV types and for different purposes [5] [6] [7] [8]. However, the data concerning combination of 3D printed plastic parts and UV-C radiation is missing or has not been published yet.

2. Materials and methods, test specimen production for UV-C tests

1.1. The research question is: how does UV-C radiation affect mechanical, tribological and the color properties of SLS printed parts? SLS 3D printer FORMIGA P100 (EOS GmbH) was used to produce all test pieces for this study. The main principle of SLS process is depicted in Figure 1.
Manufacturer of the powder is EOS GmbH. Powder average grain size: 56 μm (ISO 13320-11). Preheating temperature during the process is 171°C. The layer thickness 0.1 mm and laser power 30 W (CO2 laser) was used. Diameter of focused beam: <0.5 mm. In the process, 3D object is built by sintering powder with laser beam, section by section. The Polyamide 12 (PA2200) powder in the build platform is maintained at an elevated temperature just below the melting point and/or glass transition temperature of the powdered material. The part is supported in the process by unsintered powder. There are four different fusion mechanisms which are present in such AM processes [9]. These include solid-state sintering, chemically induced binding, liquid-phase sintering, and full melting. Most commercial processes utilize primarily liquid-phase sintering and melting [9]. Properties of the parts along layers and perpendicular to layers should be similar but in reality, they can differ considerably.

As experience shows, UV-C light changes the properties of plastic parts, including parts produced with SLS. Polyamide 12 (PA220) as the most universal material for Formiga SLS printer has proven its durability in many applications. Inside of the UV-C devices under radiations influence all material properties may change. The first and most noticeable change is in its color if parts are not covered with paint layer. However, it is not fully known how the radiation coming from UV-C disinfection systems affects the properties of the printed parts. It is also not known how the properties change depending on build position of the parts.

To study this, several tests have been made. Firstly, tensile tests to study global strength properties. Test results are discussed in chapter 3. Secondly, an impact test to focus on possible brittleness effects of UVC processing. Test results are discussed in chapter 3.1. Thirdly, surface color evaluation is discussed in chapter 3.2. Some of the tests were made on parts printed in different directions (the layer position) but vertically positioned specimens measurement uncertainty was too large [10], so more extensive study is needed, and therefore the discussion concerning those tests is skipped here.

The impact test pieces were printed accordingly to standard EN-ISO 179-1:2010 (80x10x4 mm) and tensile test pieces were printed accordingly to standard ISO 527-1:2019 (150x20x4 mm). A total of 5 test specimens were printed for each test type. Temperature on the working table during the tests was 23°C.

2.1. Test specimen surface processing
The two following paints were used to cover the surface of SLS parts: craft spray for plastics "Chrome effect" (Motip) and Dicco Color Black (Tikkurila OY). The paints were carried onto the SLS specimens by spraying ("Chrome effect") and dipping (Dicco Color Black). First, widely used “Chrome effect” was used as one layer of spray paint. The porous surface of the specimen was very suitable (Figure 2. a) for that kind of vertically positioned and dried spray-painting technology. The painted surface looked excellent as its layer covered firmly and evenly all surfaces of the test specimen.

Second paint, solvent based stain, produced by Tikkurila OY contains lightfast dyes and its viscosity is very low. The porous SLS printed specimen was dipped for 5 seconds into the black stain. Drying took place in a horizontal position on a sheet of office paper. Absorbed layer of stain is shown in Figure 2. b.
Even though it is meant for wooden materials its black matte finish looks also perfect and carefree for most PSLS details.

Finally, as known from the literature [11] that polyamide absorbs water, and the absorbed water tends to act like a plasticizer and can have a significant effect on the plastics properties, it was decided to test the mechanical properties of water dipped specimens as well. In addition, a batch of specimens were dipped into the water for 300 hours and tested without drying.

3. Results and discussion

Tensile test results.

Tensile tests have been carried out on Tinius Olsen H10KT tension-compression testing device in combination with extensometer Epsilon 3542-025M-050-ST. Preload was 0 N and speed 5 mm/min. Extensometer was used to observe precise deformation of specimen. The results are shown in Figure 3.

![Figure 3 Comparison of different specimen groups.](image.png)

The coding of specimens shown in Figure 3. is as follows:

- **T1**  Reference test specimen, not UV-C treated, not painted
- **T2**  Medium (200 h) UV-C treated specimen, not painted
- **T3**  Long (300 h) UV-C treated specimen, not painted
- **T4**  Reference specimen for painted tests, not UV-C treated, chrome effect spray paint
- **T5**  Reference specimen for painted tests, not UV-C treated, black dipped stain
- **T6**  Long (300 h) UV-C treated, chrome effect spray paint
- **T7**  Long (300 h) UV-C treated, black dipped stain
- **T8**  Water treated specimen, not UV-C treated and not painted

In first group (T1 to T3) small 10 % change in tensile strength could be noticed. Second group, painted specimens from group T4 and T5 are approximately 5% weaker than the reference specimen. Absorbed paint shows, however, that the reason for those discords could be small cracks on the surface of specimens, Figure 2. b.

It is clearly seen (Figure 2) that objects shown in the figures above have been printed horizontally. It is especially visible in the black stain, Figure 2. b.

Third group, T6 and T7, long UV-C and painted surface has almost the same values of tensile strength as the reference test specimen had. Based on that fact we can assert that painted surface has influence to the tensile strength, paint protects the 3D printed part against UV-C rays.

And lastly, the water treated specimen shows that in wet conditions we lose 10 % of the part’s tensile strength under UV-C radiation.
3.1. Impact test results
Impact test has been carried out on ZWICK Charpy impact test pendulum device. Distance between specimen supports was 62 mm and 4 different impact energy pendulums (4, 2, 1 and 0.5 J) were used regarding wide variety of needed impact energy. Results are presented below in the Figure 4.

![Impact test results](image)

**Figure 4.** Impact test results, notched specimens are placed horizontally, unnotched vertically.

The coding of specimens shown in Figure 4 is as follows:
1. Reference test specimen, no UV-C, not painted
2. Short (100 h) UV-C treated specimen, not painted
3. Medium (200 h) UV-C treated specimen, not painted
4. Reference specimens for painted test, not UV-C treated, chrome effect spray paint
5. Reference specimens for painted test, not UV-C treated, black dipped stain
6. Medium (200 h) UV-C treated, chrome effect spray paint
7. Medium (200 h) UV-C treated, black dipped stain
8. Water treated specimen, not UV-C treated, not painted

We can see same trends in first group (1, 2, 3) where UV-C treatment has good correlation with impact test results, but the difference is much bigger than in tensile tests, so UV-C treated parts are 5 to 6 times more fragile. The paint layer barely affects the results, as groups 4 and 5 have similar results with reference group no. 1. But in impact test we can see that the paint layer does not protect plastic properties as much as it protected in tensile tests. Chrome effect spray paint gives quite good results, but the black dipped stain has almost zero protection against UV-C radiation.

3.2. Surface colour evaluation
Printed details have normally white matte color. After short, 8-hour UV-C treatment they turned yellow. Longer treatment did not change color remarkably. “Chrome effect” spray paint layer gave a good protection to the surface color. Black matte stain and dipped painting technology had less value in surface protection as the stain did not form protective layer.
4. Conclusion
After 120 valid tests we can declare that UV-C has similar effect to plastics as UV-A and UV-B rays usually have. Likewise, similar protection methods like painting avoids aging in UV-C radiated parts. It is important to emphasize that the influence of UV-C and water absorption is much higher to impact strength than to tensile strength. Also, as side discovery, dipped stain painting method gives us a valuable tool for diagnosing structural defects in 3D printed plastic parts. Those defects are easily detectable after destructive tensile or impact tests.

5. References
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