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Pulsed exposure in Mask Projection Vat Photopolymerization

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Abstract
This work investigates the impact of a pulsated exposure, in comparison with the conventional continuous exposure, on one-layer samples manufactured using Mask Projection Vat Photopolymerization (MP VPP). The samples were characterized in surface appearance and geometrical measurements, indicating their curing levels, using Light Optical Microscopy (LOM). Results showed that pulsed exposure has a clear impact on the overall samples' appearance and curing level, with the shortest pulse showing the most promising outcomes. This means that pulsated exposure could improve the overall quality of MP VPP parts.

Vat Photopolymerization, DMD, pulsed exposure

1. Introduction

Undercuring or overcuring is a recurring problem encountered in Mask Projection Vat Photopolymerization (MP VPP) and stems from a lack of knowledge of its main contributors. Indeed, while the curing degree is determined by the exposure time and irradiance level, most existing research focuses on in-house equipment[1], material[2], or others, to target specific issues or applications. Consequently, it is necessary to investigate new ways to manage exposure time and irradiance.

Thus, this paper aims to examine the role of the exposure time by analyzing the impact of pulsated UV exposure versus the conventional continuous exposure on one-layer samples.

Previous work showed how conventional exposure time and irradiance impact the samples' appearance and geometry, which are intrinsically linked to their curing level[3]. However, no MP VPP study focused on pulsed exposure, although it is commonly used with AM processes involving lasers and achieves a higher overall part quality[4].

2. Methodology

The current investigation involved the manufacturing and characterization of one-layer samples to study the impact of the exposure ON/OFF pulse cycle. The specimens were additively manufactured using an in-house photo projector equipped with a Digital Micromirror Device (DMD) and fit for MP VPP, which projected UV light at a wavelength of 385 nm. They were then characterized using LOM to observe changes in their appearance and get their geometrical measurements. Their widths and heights were multiplied to obtain their area, and then their standard deviations.

Batches of five one-layer samples were manufactured using an in-house setup, presented in Figure 1. Each batch was subjected to UV for the same time, but with different ON/OFF pulse frequencies. For the conventional exposure, specimens were irradiated by a UV square pattern for two continuous seconds while for the pulsed exposure, it was for four seconds, as there is no UV between the pulses.

The different pulse durations were one, ten, or hundred milliseconds. They were chosen as they are two orders higher than the LED's intrinsic cycle, which avoids creating interferences. Three different irradiance levels were used: low, medium, and high.

The material used was Industrial Blend by FunToDo and the samples' post-processing included thorough isopropanol (IPA) rinsing, followed by UV post-curing for one minute.

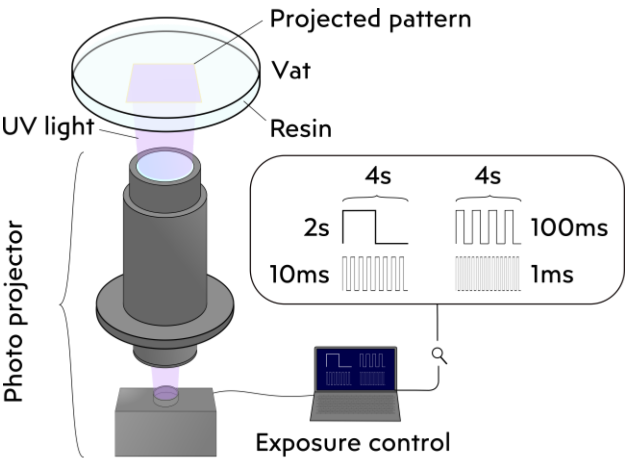

Figure 1. Illustration of the setup including the in-house photo projector, projection lens, resin, vat, and exposure control system.

3. Results

The results are presented in the form of selected LOM pictures for each batch of samples, see Figure 2, as well as their geometrical measurements, displayed in Figure 3.

Figure 2 shows that, as expected, substantial differences are exhibited regarding the parts produced at various irradiances. Lower irradiance specimens are undercured: thin with a tendency to curl, reflective surfaces, and tears in places. Medium irradiance specimens are thicker, and their base surface is shiny. High irradiance specimens are overcured: even thicker, with a tendency for their corners to lift, and a reflective base.

The LOM pictures also display a general tendency for the surface appearance to improve as the pulses get shorter, from left to right. Defects such as heavy tears or cracks, which are generally a consequence of undercuring, can be observed in all samples exposed to the conventional continuous exposure (far left column). However, as the radiation pulse gets shorter (from left to right), the defects reduce in size or even disappear. The overall smoothness and surface uniformity increase in the same manner as well.

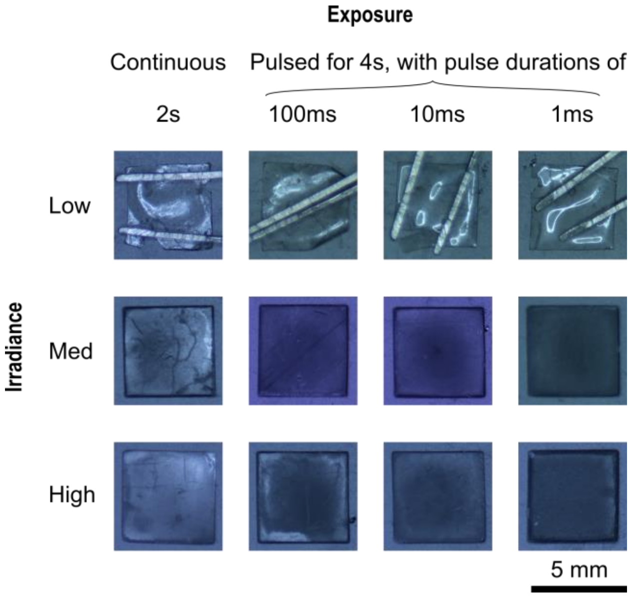

Figure 2. LOM pictures of one sample from each batch with different irradiance levels horizontally, and exposure types vertically.

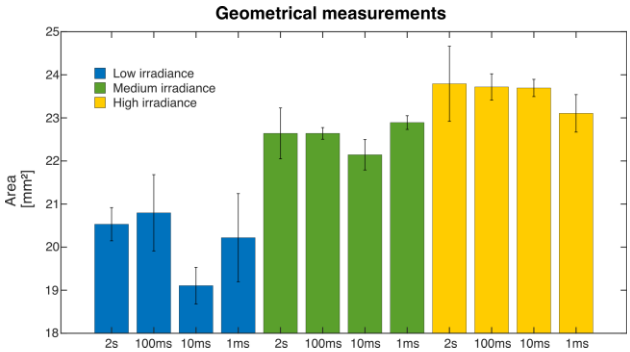

Figure 3. Bar charts of the samples' area and their standard deviations at low, medium, and high irradiance (from left to right) for each exposure time. Where 2s refers to the convential continuus UV radiation while 100ms, 10ms and 1ms relate to the pulse duration.

Figure 3 presents the surface area and standard deviation for each batch of samples. As expected, a lower irradiance also indicates a smaller surface area, therefore a lower degree of curing. The larger standard deviations for some samples can be explained by their curved surface or corners' tendency to lift.

In the case of low and medium irradiances, the area seems to stay the same for specimens exposed for two seconds and the ones produced with a hundred milliseconds pulse, have a drop in size at ten milliseconds, and approximate the first two values for a one millisecond pulse.

In the case of high irradiance, the first three parts seem to reach a plateau, possibly due to overcuring, before showing a reduction in size for the fourth one.

Interestingly, both samples exposed to the one millisecond pulse for medium and high irradiance appear to have the same surface area, and therefore the same level of curing. This could mean that this is the maximal level of curing achievable with this pulse.

4. Discussion

The results clearly show that the exposure type, continuous or pulsed, affects both the samples' surface appearance and curing level. As the pulse gets shorter, the defects decrease in number and volume while the overall smoothness increases. This suggests that small bursts of energy, each followed by a dark time, have a protective effect on the specimens, similar in practice to the one observed with AM involving pulsed lasers. This could also explain why, at high intensity, the shortest pulse produced smaller samples than other pulse durations.

When considering the continuous exposure of two seconds as a pulse with an equal dark time of two seconds, it is possible to compare the average power levels of all samples manufactured at the same intensity. For a distinct level of irradiance, as all samples are exposed to UV for the same total time, the average power is also equal. This indicates that despite being subjected to the same quantity of energy, the specimens behaved differently. The only difference lies in the duration of pulses and dark time, which means that this ON/OFF pulse cycle plays a crucial role in the manufacturing process.

5. Conclusion

Pulsed exposure has a clear impact on the samples' appearance and size. Indeed, samples manufactured with shorter pulses display fewer defects, an overall smoother surface, and less degree of overcuring compared with conventional exposure. This means that using a pulsed exposure, as opposed to the conventionally continuous one, could improve the overall quality of MP VPP parts.

More research on this phenomenon is crucial and future work could encompass increased dark times, to study how the resting phase affects the final product, or reproduce the same work with different ranges of intensities, pulse durations, duty cycles, or material.

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