Surface Binding Ability in Photoinitiator Polymer Systems

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Objectives

Determine the optimal curing time and binding strength for 3 photoinitiator- containing polymers: hydroxycyclohexyl phenyl ketone, benzophenone, and dimethyl (2,4,6-trimethyl benzoyl) phosphine oxide on borosilicate glass, aluminum, and birchwood.

Background & Research

Polymer curing begins when UV light activates a photoinitiator, breaking double bonds in monomer chains to form unstable carbon radicals that link with adjacent monomers, repeating until polymerization completes (James & Zarate 2022).

Photoinitiators enable UV-free polymerization using visible LED light in 3D printing, enhancing safety by reducing skin exposure and eliminating stair-casing defects in 3D printing. Dental innovations now allow faster curing with less light (Jędrzejewska & Pyszka 2024). Performance varies by photoinitiator type, affecting bond strength and applications.

Beyond cosmetics (like gel nail polish), these polymers can be used in construction and industry as a cost-effective temporary repair solution for damaged hardware.

Results & Limitations

- All photoinitiator samples showed the strongest binding ability when bound to borosilicate glass between 15-20 seconds cured. This result could be due to the transparency of the glass, which allowed for UV to fully penetrate, as well as the low surface energy of the sample which further encouraged polymerization.
- With aluminum, dimethyl (2,4,6-trimethyl benzoyl) phosphine oxide showed the greatest pressure withstood with an average of 4.47 lbs. and a standard deviation of 2.93 lbs.
- Hydroxycyclohexyl phenyl ketone and benzophenone withstood 1.95-2.5 lbs. of pressure when bonded to aluminum. The high surface energy in aluminum is thought to have resulted in poor adhesion.
- Birchwood showed very low results for pressure withstood with each photoinitiator sample. This is thought to be due to birchwood's porosity, which could have hindered proper binding during the polymerization reaction. Each sample only withstood .96-1.9 lbs. in the three trials.
- Throughout the course of this experiment, limitations were met. Regarding the spectrophotometer, photoinitiator samples were sometimes too thickly applied to sample surfaces, causing the seeping of polish when pressure was applied via diamond tip.
- The spectrophotometer later became impaired during spectra collection, leaving it unavailable for use.
- The SUNUV lamp could have inaccurately measured time
- Data collection is still ongoing for glass pressure testing.

Implementation

- Photoinitiator samples came in the form of gel nail polish samples, all including white pigments. Polishes contained Benzophenone, Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide, Hydroxycyclohexyl Phenyl Ketone, and a non-photoinitiator polish.
- Surfaces tested included borosilicate glass, aluminum, and birchwood. In the form of lab slides, aluminum sheet metal, and popsicle sticks
- A Thermo Scientific Unity Lab Services Spectrophotometer was used to collect background spectra for each surface after prepping with acetone and cleaning the diamond tip with methanol.
- Afterward, even layers of each gel nail polish sample were applied to each sample surface. IR was measured while all gel nail polish samples were uncured and wet
- Using the SUNUV lamp (operating at 398 nm of UV and 405 nm of LED light), gel nail polish samples were cured in 12 5-second increments, using the built-in timer. IR was measured between each 5-second increment to observe patterns of wavelength absorption. The two "best" and "worst" curing times were recorded based on the graphical appearance of spectra. The average drying time was tested for the control group on each surface. Spectra were not collected for the control group.
- Holes were drilled/cut into the aluminum and birchwood samples to allow for proper access to the hook from the scale. The supposed optimal, worst, and ideal/control curing time of 60 seconds per polish was then strength tested.
- Each sample surface was prepped with acetone before strength testing. Surfaces were bonded together with each photoinitiator at the different recorded curing times. An ANGEL POS hanging scale was then used to measure the pressure used to pull bonded surfaces apart. Three trials were run for each nail polish sample during pressure testing.

Materials used

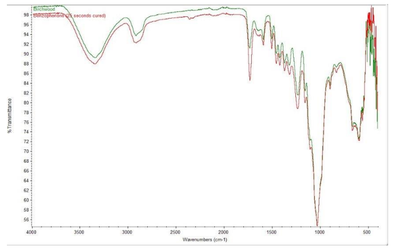
ThermoScientific Unity Lab Services Spectrophotometer

Control Group Data:

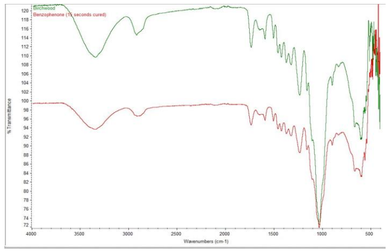
- Drying time on borosilicate glass:
  - Average of 8 minutes
- Drying time on birchwood:
  - Average of 3.59 minutes
- Drying time on aluminum:
  - Average of 6.12 minutes

Pressure withstood by the control group:

- Borosilicate glass:
  - Average of .083 lbs
- Birchwood:
  - Average of .05 lb
- Aluminum:
  - Average of 1.69 lbs



Recorded "best" curing time for benzophenone when cured on birchwood



Recorded "worst" curing time for Benzophenone when cured on birchwood

BOROSILICATE GLASS CURING TIMES:

"Best" curing times for Borosilicate Glass:

Benzophenone:
15 seconds
10 seconds

Hydroxycyclohexyl phenyl ketone:
20 seconds
15 seconds

Dimethyl (2,4,6-trimethylbenzoyl) Phosphine Oxide:
55 seconds
40 seconds

"Worst" curing times for Borosilicate Glass:

Benzophenone:
60 seconds
35 seconds

Hydroxycyclohexyl phenyl ketone:
30 seconds
40 seconds

Dimethyl(2,4,6-trimethylbenzoyl) Phosphine Oxide:
10 seconds
5 seconds

ALUMINUM CURING TIMES:

"Best" curing times for Aluminum:

Benzophenone:
15 seconds
20 seconds

Hydroxycyclohexyl phenyl ketone:
20 seconds
55 seconds

Dimethyl (2,4,6-trimethylbenzoyl) Phosphine Oxide:
15 seconds
20 seconds

"Worst" curing times for Aluminum:

Benzophenone:
60 seconds
15 seconds

Hydroxycyclohexyl phenyl ketone:
15 seconds
40 seconds

Dimethyl (2,4,6-trimethylbenzoyl) Phosphine Oxide:
25 seconds
50 seconds

BIRCHWOOD CURING TIMES:

"Best" curing times for Birchwood:

Benzophenone:
50 seconds
25 seconds

Hydroxycyclohexyl phenyl ketone:
25 seconds
40 seconds

Dimethyl (2,4,6-trimethylbenzoyl) Phosphine Oxide:
25 seconds
40 seconds

"Worst" curing times for Birchwood:

Benzophenone:
60 seconds
15 seconds

Hydroxycyclohexyl phenyl ketone:
5 seconds
10 seconds

Dimethyl (2,4,6-trimethylbenzoyl) Phosphine Oxide:
5 seconds
10 seconds

Research Continuation

This experiment could be recreated using greater tools to avoid inaccuracy, testing faults, as well as employ research on how the melting point of photoinitiator-containing polymers varies per surface, as surface energy contributes to the bond strength and physical properties of polymers. Lastly, the research conducted by manufacturing engineer, Joel Zarate, on photoinitiator polymerization in 3D prints is a great avenue for the use of photoinitiator products to be further expanded. The photoinitiator used in his research- Bis(2,6-Difluoro-3-(1-Hydropyrrol-1-Yl) Phenyl)Titanocene warrants further investigation due its ability to promote polymerization at visible light. Optimizing this compound could advance both industrial applications, and creative domains.

References

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Conclusions

The results demonstrate that spectral data do not always correlate with optimal bonding behavior. Collected spectra frequently identified the 50-60 second range as the least effective curing interval, attributed to varying light absorption dynamics across surfaces. However, experimental data revealed that the ideal curing time (60 seconds) maximizes performance on porous or high-energy surfaces. Photoinitiated polymers exhibit exceptional utility in glass-intensive industries, with experimental results consistently achieving high bonding strengths.

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