WHITE PAPER

A Guide to Post-Curing Stereolithography (SLA) 3D Prints

Post-curing is key to reaching the mechanical properties you expect from your resin 3D printed parts. Through the application of heat and light, the strength and stability of printed parts improve beyond their original “green” state. However, each resin behaves slightly differently when post-cured, and requires different amounts of time and temperature to arrive at the material’s optimum properties.

With Form Cure and Form Cure L, SLA 3D printed parts can be post-cured at precisely the correct wavelength, at different temperatures, and for varying lengths of time. In this white paper, learn the basics of post-curing and how to adjust your process to save time and achieve the best performance.

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Abstract

Each Formlabs Resin is formulated with advanced, light-sensitive polymer chemistries. Formlabs stereolithography (SLA) 3D printers, such as the Form 3+, Form 3B+, Form 3L, and Form 3BL use 405 nm lasers to cure the liquid resin, producing a highly accurate solid part.

When an SLA part finishes printing, it remains on the build platform in a “green state.” This means that while parts have reached their final form, polymerization is not yet fully completed and the part has yet to attain maximum mechanical properties. Post-curing with light and heat is key to unlocking this last mile of material properties for SLA 3D prints. For biocompatible materials, post-curing is necessary to achieve the safety standards determined by regulatory agencies.

Achieving optimal properties is especially essential when using functional or specialty resins. Form Cure and Form Cure L, the two post-curing solutions from Formlabs, are designed to post-cure parts printed in Formlabs Resins with speed and consistency. Our engineers developed Form Cure and Form Cure L specifically to work with Formlabs Resins, using the same 405 nm light as the lasers in Formlabs SLA 3D printers. Parts are heated and automatically rotated in the reflective chamber to ensure an even and consistent post-cure.

This guide will help you understand how post-curing affects the key properties of Formlabs materials. We’ll cover post-curing recommendations for material-specific applications, as well as strategies for avoiding common issues.

Formlabs releases new materials and resin reformulations periodically. This guide doesn't include post-cure recommendations for all Formlabs resins that are currently available. Visit our website to see up to date information on all our materials for Form Cure and for Form Cure L.

Introduction to Post-Curing Science

Any resin used in SLA 3D printing can be thought of as a highly cross-linked macromolecule, or a continuous network of polymer chains (monomers and oligomers). Within that macromolecule, there are still some reactive groups that can further cross-link the polymer network when exposed to light and heat.

As more cross-links form, material properties, such as modulus and tensile strength, improve. The objective of post-curing is to link as many of these unreacted groups as possible to bring a part to its maximum material properties.

Once optimal material properties are reached, further post-curing of certain resins can sometimes cause brittleness or warping. The post-curing protocol must therefore be specific for both time and temperature in order to avoid curing too much, and will be unique to each resin and part geometry.

Optimal post-curing starts with heat. Rising temperatures increase the energy, and therefore mobility, in the polymer network. This gives reactive groups a higher probability of finding each other and creating more connections. Formlabs post-curing machines, the Form Cure and the Form Cure L, both use a heater to help the curing chamber quickly reach the desired temperature and then maintain it throughout the postcure.

Once the desired temperature is reached, light is introduced. Photons of light activate remaining photoinitiators, causing nearby reactive groups to form bonds and finish the cross-linking process. With each new cross-link the polymer network becomes more securely linked together and material properties improve.

As more cross-links form in the resin, the network slightly densifies, resulting in some minor shrinkage of the whole part. This is normal for any parts produced with a resin 3D printer. PreForm, Formlabs' free print file preparation software, automatically compensates for this shrinkage to ensure your post-cured prints are dimensionally accurate to your original CAD designs.

Post Curing Hardware

Formlabs released the first post-cure hardware product made specifically for Formlabs resins, the Form Cure, in early 2017. With pre-set time and temperature settings for each of the Formlabs resins, it takes the guesswork out of the post-cure process, and also enables users to safely print biocompatible resins that meet the requirements for the biocompatible class or device.

The Form Cure uses a 405 nm light source, which was determined through an extensive internal testing process to be the most effective at creating the best modulus and tensile strength in parts printed on Formlabs printers. In comparison, when the time and temperature were the same, but a 365 nm light source was used, the modulus reaches only 67% as that of the 405 nm samples. There is a significant difference in the post-cured properties at each wavelength, especially so at shorter post-cure times.

In order to create the same streamlined and efficient workflow for larger format SLA printers, Formlabs released the Form Cure L in late 2021. It is designed to produce parts with equivalent material properties as the ASTM method test specimens reported in our technical datasheets, and ensures the dental and medical materials achieve all standards of biocompatibility.

More than double the size of the Form Cure, the Form Cure L has two 405 nm light sources and presets for each resin. When new resins are released, users simply update the firmware on their Form Cure L to get the specific time and temperature for optimal material properties. For applications such as creating large molds for injection molding with Rigid 10K Resin, post-curing the full part is absolutely essential. The Form Cure L opens the door for new applications by providing an end-to-end solution for large parts.

Though the Form Cure L has the size to post-cure large parts, it can also be used to efficiently post-cure many small parts for batch production. A dental lab may have five Form 3B+ printers, but need only one Form Cure L to cure all their parts at once. Having a single Form Cure L means that production volumes can be reached, without investing in expensive manufacturing technology.

In the reverse scenario, a jeweler who prints a hundred models on the Form 3L, but needs to cure only a few at once and doesn't have the budget to purchase a Form Cure L, can purchase the Form Cure and still create the same streamlined workflow

	FORM CURE	FORM CURE L
Printer Compatibility	Form 3+, Form 3B+, Form 2	Form 3L, Form 3BL, Form 3+, Form 3B+, Form 2
Turntable Diameter	19.3 cm 7.6 in	39.5 cm 15.6 in
Maximum Part Height	18.5 cm 7.28 in	32 cm 12.6 in
Ideal For	Small to medium-sized parts Scaling operations in multiple locations	Large parts Batch production of smaller parts Single curing unit for multiple printer builds

Biocompatible Materials and Post Curing

As more dental and medical professionals adopt 3D printing in their workflows, 3D printing companies have to ensure that the entire process is controlled to consistently manufacture high performing parts with biocompatible safety for the end user. Biocompatibility requirements require careful adherence to these pre-approved processes, and this applies to the post-cure step of the printing process as well.

Formlabs technology has been validated in FDA-cleared workflows, which means that for each resin intended for use in a biocompatible application, there are certain printing, washing, and curing steps that must be followed without deviation in order for the final part to be considered a biocompatible device.

The Form Cure and Form Cure L are important parts of these workflows. After careful testing and a thorough regulatory process, the validated settings for post-cure times ensure that each printed part for biocompatible applications has optimal mechanical properties and is consistently safe for use.

Find specific post-curing recommendations for each material in our step-by-step dental application guides or download the instructions for printing for medical applications.

Methodology

An ideal post-cure setting achieves the properties you need in the most optimized amount of time. For Standard Resins (White, Grey, Black, and Clear), this amount may be none at all, or a short 15 minute post-cure. Where strength, rigidity, and temperature resistance are needed, Formlabs Engineering Resins improve with post-cure of up to 120 minutes.

Formlabs developed an in-house post-cure study to identify optimized settings for each individual Formlabs Resin. Using the ASTM method, our materials scientists tested a variety of mechanical properties at various temperatures for each material.

To see how post-curing influences mechanical properties, this guide looks at changes in the tensile modulus, which shows a change in stiffness of a part, for each resin over time in Form Cure or Form Cure L. An object with a higher tensile modulus will have a greater resistance to changing shape under stress. Modulus of elasticity is closely related to how completely crosslinked photopolymer chains are within the part, which is why Formlabs uses modulus to represent overall completeness of post-curing.

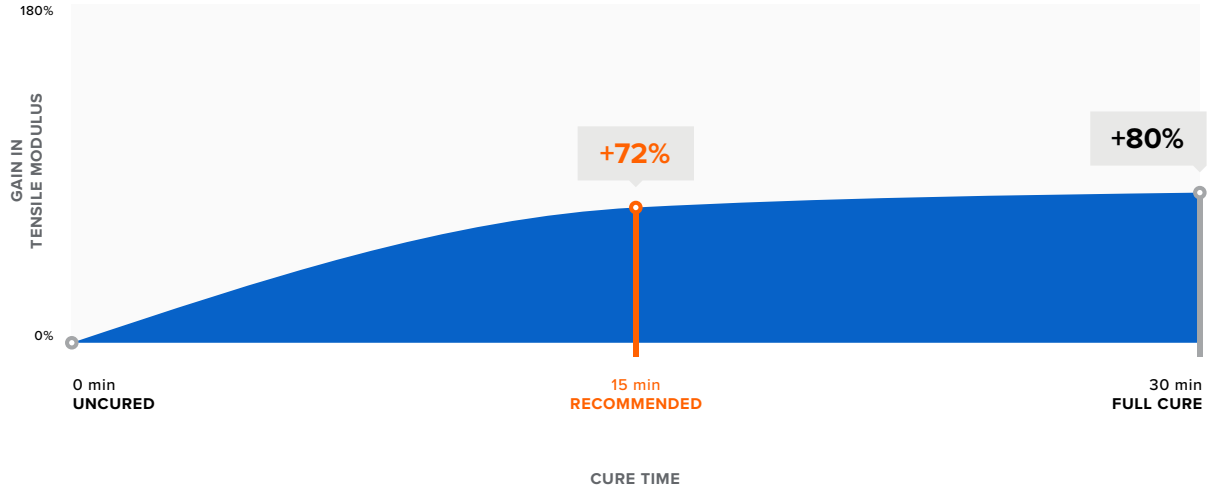
The “green” shape of a model is formed by laser-curing the resin during printing, but some potential polymer connections remain unbonded. Cross-linking the remaining polymer proportionally improves strength, stiffness, and temperature resistance. Post-curing also causes some part shrinkage. Formlabs measures accuracy and mechanical properties based on a standard post-cure of parts, and material settings are tuned to account for shrinkage under the same conditions.

The following graphs will help you understand how Formlabs materials respond to post-curing, viewed as a percentage increase in tensile modulus. Familiarity with post-curing behavior saves time and improves accuracy when post-curing parts for your particular application.

Find all up-to-date recommended post-cure settings for Form Cure or Form Cure L on our website. Material data sheets with specific mechanical properties after the recommended post-cure are available for download on our website.

RECOMMENDED POST-CURE SETTINGS

Clear Resin



Analysis: Post-Curing Optional

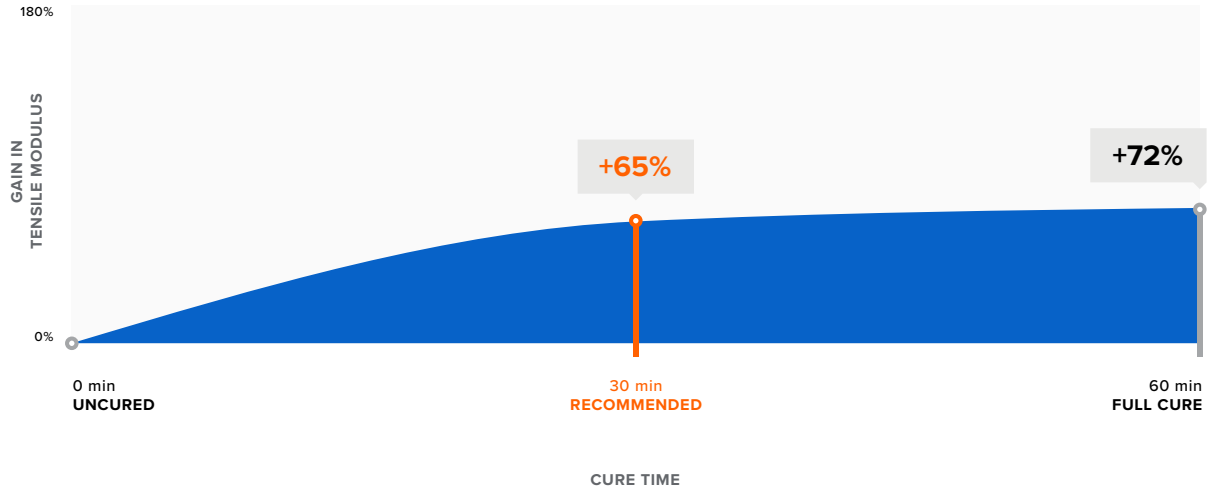
Clear Resin shows a sharp increase of 72% in tensile modulus in the first 15 minutes of post-cure, which gives way to a gradual increase over the next 15 minutes. Maximum mechanical properties are reached at 30 minutes.

APPLICATIONS GUIDELINE

When used for visual prototypes and models, Standard Clear Resin only requires washing and air drying. A 15 minute post-cure can be helpful to eliminate surface tackiness, increase surface hardness, and improve scratch resistance. If you expect to mechanically stress or heat your part, such as in a fixture or thermoform mold, post-cure for the full 30 minutes to minimize deformation. In order to avoid excessive color change, limit post-curing of Clear Resin to 30 minutes.

RECOMMENDED POST-CURE SETTINGS

White, Grey, & Black Resin



Analysis: Post-Curing Optional

Formlabs opaque Standard Resins (White, Grey, and Black) have similar composition and post-curing characteristics. When post-cured at 60 °C, the modulus of elasticity shows a fast, 15-30 minute initial post-cure phase, followed by a gradual increase up to a maximum modulus at 60 minutes.

APPLICATIONS GUIDELINE

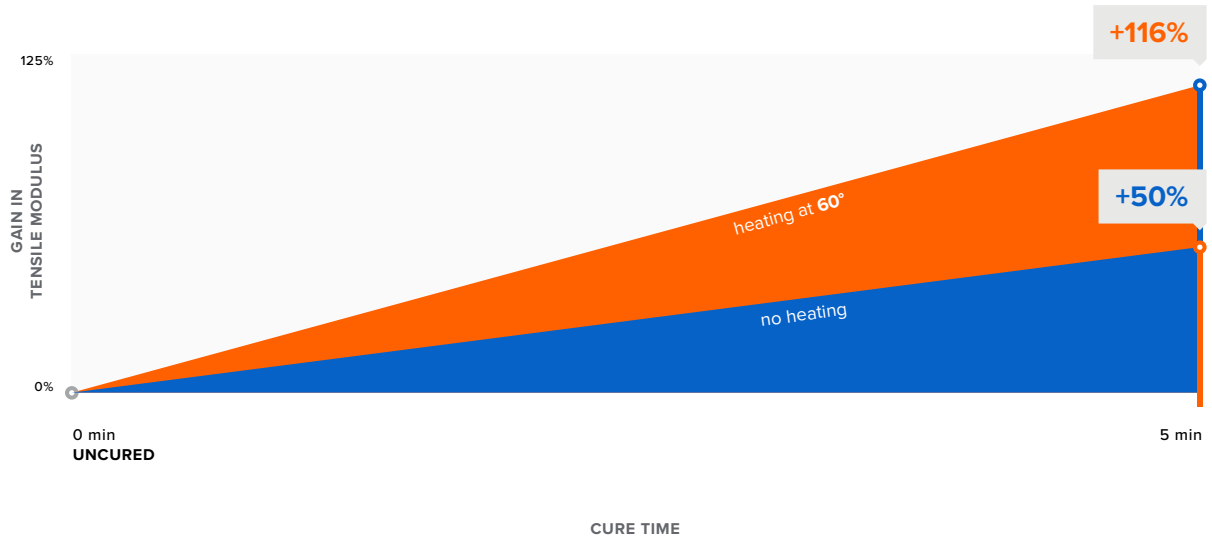
Opaque Standard Resins post-cure slightly slower than Clear Resin. In most cases, Standard Resins only require washing and air drying. A 30 minute post-cure can be helpful to eliminate surface tackiness, increase surface hardness, and improve scratch resistance. If you expect to mechanically stress or heat your part, such as in a fixture or thermoform mold, post-cure opaque Standard Resins for 60 minutes at 60 °C. Post-cure Color Kit with the same procedure as Standard Resins.

FAST POST-CURE

Recommended for display models and static prototypes.

RECOMMENDED POST-CURE SETTINGS

Draft Resin



Analysis: Post-Curing Optional

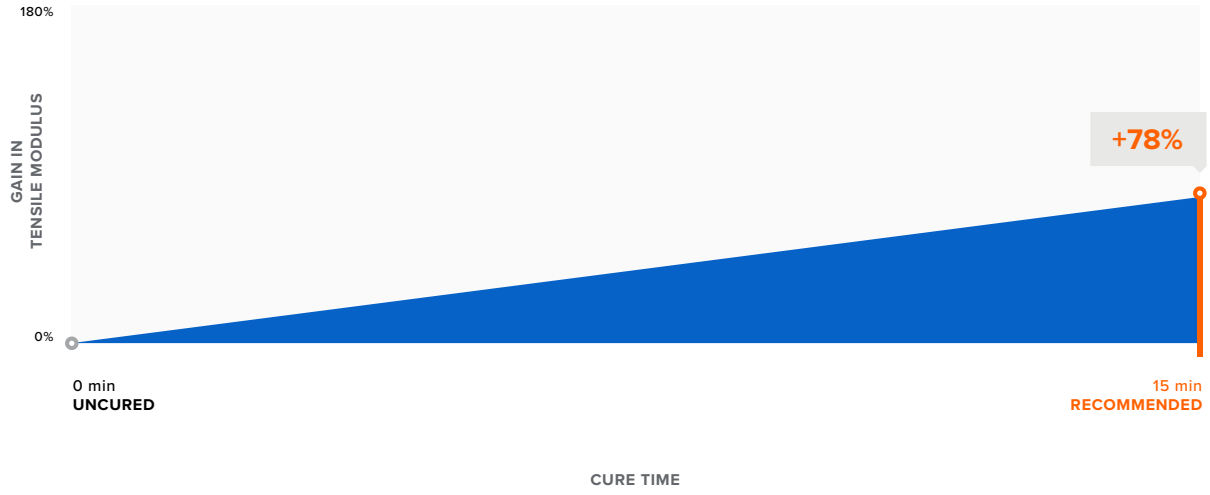
For Draft Resin tensile modulus increases steadily when undergoing a five minute post-cure both with and without heat. The gain in tensile modulus is 50% when curing without heat, and 116% when curing with heat. The primary goal of post-curing draft is to eliminate surface tackiness from parts, which is accomplished with both an unheated and heated post-cure protocol.

APPLICATIONS GUIDELINE

When used for visual prototypes and models, Draft Resin only requires washing and air drying. A five minute post-cure eliminates surface tackiness, increases surface hardness, improves scratch resistance. If you expect to mechanically stress or heat your part, such as in a fixture or thermoform mold, post-cure for five minutes with heat to minimize deformation.

RECOMMENDED POST-CURE SETTINGS

Grey Pro Resin



Analysis: Post-Curing Strongly Recommended

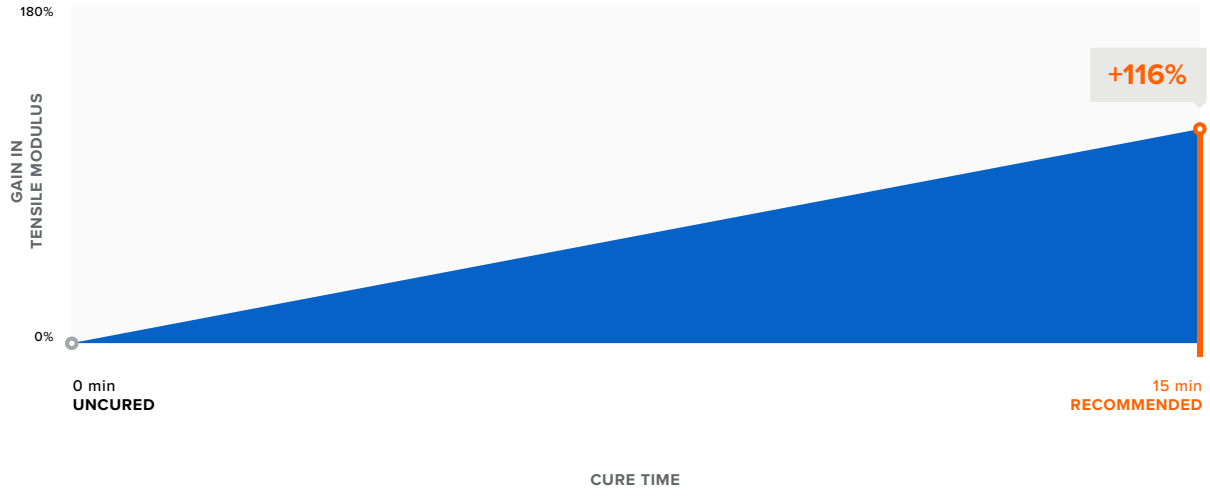
When post-cured at 80° C, Grey Pro gains a substantial 78% increase in modulus of elasticity after 15 minutes. After 15 minutes this reaction is essentially complete, and modulus does not increase except for a small rise between 30 and 45 minutes of exposure.

APPLICATIONS GUIDELINE

Grey Pro Resin should be post-cured for 15 minutes at 80 °C in order to harden the surface and develop expected strength characteristics. While post-curing beyond 15 minutes is generally not needed, thick or bulky parts may benefit from a longer post-cure time in order to ensure that the model has completed the main post-curing reaction throughout.

RECOMMENDED POST-CURE SETTINGS

Rigid 4000 Resin



Analysis: Post-Curing Strongly Recommended

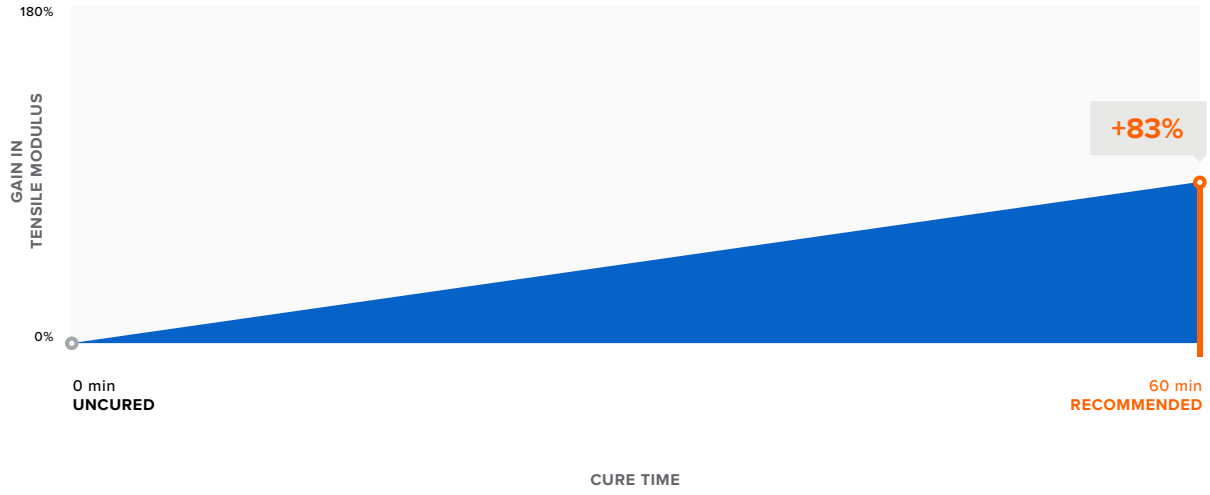
Rigid 4000 Resin exhibits a sharp rise in modulus of elasticity over the first 15 minutes of post-curing, increasing by 116%. After 15 minutes, no further improvements are observed.

APPLICATIONS GUIDELINE

Rigid 4000 Resin is a glass-filled composite material designed for parts requiring high stiffness and strength, as well as low deformation under load. Post-cure directly increases strength and stiffness by further crosslinking the polymer matrix surrounding microparticles of glass, holding them rigidly in place. Post-cure of Rigid 4000 Resin is substantially impacted by temperature. At higher temperatures, a large improvement in modulus of elasticity is gained over a short period of time. Post-curing beyond 15 minutes will not affect properties but will begin to cause cosmetic yellowing, and is not recommended. For most applications of Rigid 4000 Resin, post-cure for 15 minutes at 80 °C in Form Cure.

RECOMMENDED POST-CURE SETTINGS

Tough 2000 Resin



Analysis: Post-Curing Recommended

Tough 2000 Resin shows an 83% increase in tensile modulus after 60 minutes of post-curing. There is no significant gain in properties after 60 minutes.

APPLICATIONS GUIDELINE

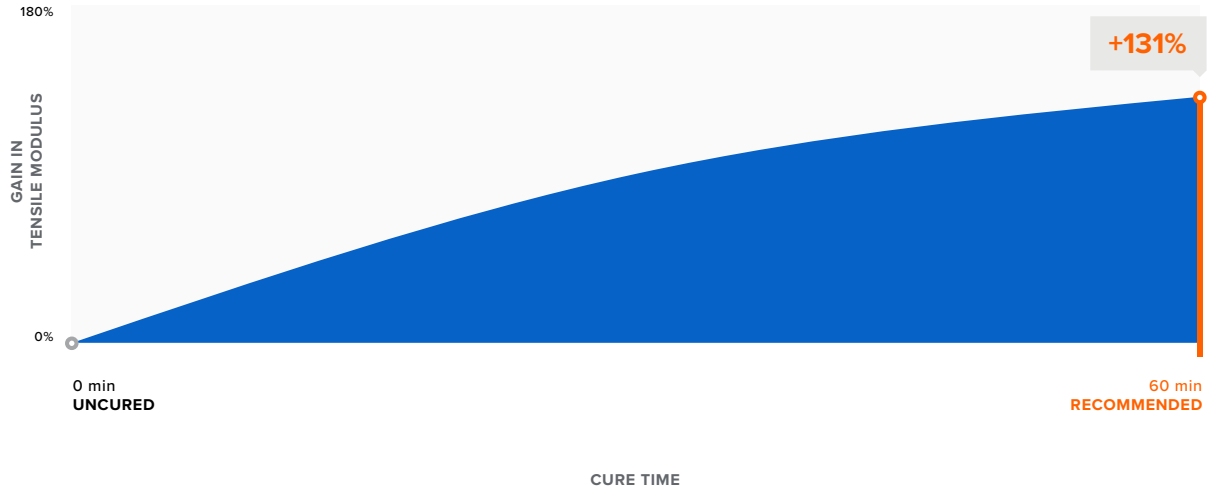
Tough 2000 Resin balances strength and compliance, making it the ideal choice for prototyping strong, functional parts. Tough 2000 excels in mechanical applications where a load is applied over time, such as mounts, fixtures, brackets, and structural enclosures.

Plastic parts tend to slowly creep under a sustained force. Post-curing is a good way to increase the strength and rigidity of a Tough 2000 part beyond what is immediately necessary to carry a load. This margin reduces the rate of creep and increases the lifespan of your parts. The increase in mechanical properties from post-curing is significant: at 60 minutes at 70 °C in Form Cure, the flexural stiffness of Tough 2000 Resin increased more than fourfold from 0.45 GPa to 1.9 GPa, and flexural strength increased similarly from 17 MPa to 65 MPa. These properties approach the stiffness and strength of injection molded ABS plastic.

Tip: Modifications such as drilling and machining are easier on a softer “green” part. Post-cure Tough 2000 Resin after modifications are made.

RECOMMENDED POST-CURE SETTINGS

Durable Resin



Analysis: Post-Curing Recommended

Durable Resin exhibits a two stage post-cure. Modulus of elasticity increases to 68 percent of maximum over 15 minutes, followed by a plateau and a second significant increase occurring between 30 and 60 minutes. Maximum modulus is reached at 60 minutes. Beyond 60 minutes, chances of part deformation increase without an increase in properties.

APPLICATIONS GUIDELINE

Durable Resin produces parts with a smooth, glossy finish and high resistance to deformation. With post-curing, Durable becomes significantly stiffer and stronger, while remaining very resistant to breakage. Higher stiffness and flexural strength allow Durable to perform well for snap fits and flexure features, where a part is subject to cyclic loading and unloading. Applications such as joints and bushings require excellent surface durability. A fully cured surface helps reduce tribological wear and maintains better tolerances over time. For most applications of Durable, Formlabs recommends a full 60 minute post-cure.

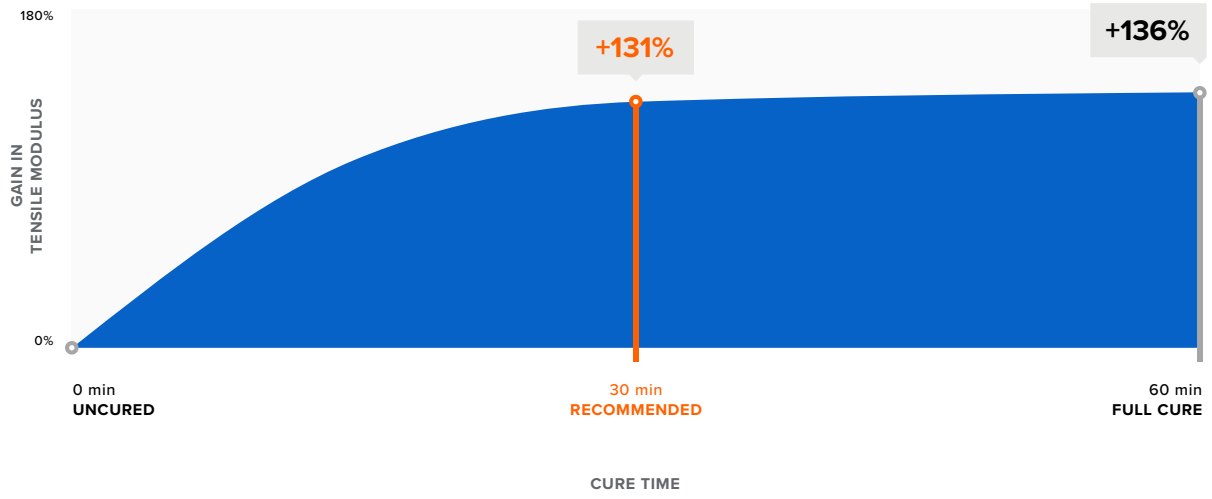
FAST POST-CURE

If engineering requirements demand only flexibility and impact strength, a short 15 minute cure may be a smart compromise to simulate a softer, impact-modified polypropylene. A clean isopropyl alcohol (IPA) wash will help improve surface durability and reduce tackiness when using a shorter post-cure.

Warning: Durable parts that are not fully cured have lower heat resistance, and will be more likely to creep or deform over time.

RECOMMENDED POST-CURE SETTINGS

High Temp Resin



Analysis: Post-Curing Strongly Recommended

There are several post-curing options for High Temp v2. Refer to the technical data sheet to understand how different options affect mechanical properties, and choose the post-cure option that is best suited to the intended application. To achieve the highest HDT of 238 °C @ 0.45 MPa: (1) Post-cure parts in Form Cure for 120 min at 80 °C. (2) Thermally post-cure parts in a non-food oven for 3 hours at 160 °C. For applications that do not require the maximum heat resistance, post-cure parts in Form Cure for 60 min at 60 °C.

APPLICATIONS GUIDELINE

High Temp Resin is intended for low-impact, high-temperature applications such as heater ducts, high temperature millifluidics, and thermoforming. Post-curing is essential for High Temp; the heat deflection temperature of High Temp starts at 49.3 °C and climbs to 238 °C with a complete post-cure. While many resins show signs of thermal shock when placed in sudden direct contact with hot materials such as gas or molten plastic, post-cured High Temp Resin can withstand temperatures near its HDT without degradation.

Tip: High Temp Resin will change color from a light yellow to orange to indicate the extent of post-curing.

Post-Cure Troubleshooting

The most common issues encountered when post-curing parts are under-curing and warping. If parts seem weaker or less rigid than expected, they may be insufficiently post-cured.

Undercuring can occur when a part is particularly thick or large, as larger parts take longer to heat. Light alone cannot post-cure much beyond the surface of a part, which is why Form Cure and Form Cure L apply both heat and light. If a part is significantly larger or thicker than Formlabs' test geometries, it may require a longer post-curing time or higher temperatures to reach a full internal post-cure.

Warping during post-cure may occur if a part is especially thin, and is not equally exposed to light on all sides. Form Cure and Form Cure L help prevent warp by rotating the part on a turntable during post-curing, and by exposing the part to light from all directions—including underneath the turntable.

Post-cured parts also tend to be more brittle than green parts. While the graphs in this white paper focus on changes in modulus, typically, as modulus increases elongation will decrease. Because of this, over-cured parts can be undesirably brittle .

Conclusion

Formlabs makes it easy to complete your SLA 3D printing workflow with large volume and small volume curing options. After extensive internal and externally validated testing, the Form Cure and Form Cure L make scaling SLA production easier than ever.

Pre-determined settings for each Formlabs resin help your parts reach their optimal material properties, finalize the professional surface finish that customers expect, and decrease the labor time involved in post-processing.

Find out more abot our post-curing solutions on our website or contact Formlabs experts if you have any questions.

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