# Residual Stresses in Stereolithographic Models

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## Abstract

This paper discusses some of the problems which may be encountered during Rapid Stress Analysis (RSA), a technique where experimental measurements (strain gages, optical methods, etc.) are made directly on stereolithographic (SLA) models. Results show that the residual stresses vary from machine to machine and, for a particular resin and build style, depend upon the build direction. Their presence makes it difficult to measure material properties from calibration specimens and impossible to obtain accurate quantitative data from complex models and assemblies without taking them into account.

## Introduction

The method of stereolithography [1] was developed in the U.S. during the late 1970s and 1980s. It involves translating a CAD drawing to a solid model by directing a computer controlled ultraviolet laser onto a vat of liquid photopolymer. Where the photopolymer is sufficiently exposed to the laser beam, it hardens down to a regulated depth. After each pass of the laser, the platform on which the part rests is lowered until a solid model is constructed. The SLA (stereolithography apparatus) model provides a visualization tool for the designer and may serve to produce a mold for casting parts out of engineering materials. The molds can be used to produce short-run production parts that can be tested to obtain experimental data (contours, stresses, boundary conditions, etc.) sufficient to verify and/or tune computer aided design tools and finite element analyses.

In 1991, it was first reported that the materials used to build SLA models displayed the characteristics required for photoelastic analysis [2]. At the same time, it was suggested that direct measurements, made on an SLA model using a polariscope, could be related through proper scaling to the stress state which occurred in a functional prototype machined or cast from another engineering material. This method, which Dr. Neal Enke of Ford Motor Company called Rapid Stress Analysis (RSA), prompted other groups to make direct measurements on SLA models using a variety of techniques including the method of photoelasticity [3,4]. However, the measurements taken from SLA models did not always agree with the data extracted by other means [5]. In virtually all cases, researchers assumed that the residual stresses created in SLA models during the fabrication process were so small that they could be neglected. However, there is substantial evidence to the contrary; so much so, that researchers are beginning to reconsider this claim [6].

This paper discusses some of the findings reported during RSA [7,8] and describes preliminary tests conducted to study the residual stresses in SLA models. Results show that the residual stresses vary from machine to machine and, for a particular resin and build style, depend upon the build direction. Their presence makes it difficult to measure material properties from calibration specimens and impossible to obtain accurate quantitative data from complex models and assemblies without taking them into account.

## Experimental Work

A study was performed on two types of specimens; tensile specimens having 12.7 mm x 3.18 mm (0.5" x 0.125") rectangular shanks, and 2.54 mm (0.1") thick, 25.4 mm (1") diameter disks. The specimens were produced using SL 5170 epoxy resin using the ACES (Accurate Clear Epoxy Style) build style. They were either grown through the thickness (face-up), or through the width/diameter (side-up) by three different organizations: Alabama Industrial Development Training (AIDT and labeled as A in the figures), Fasted Corp. (labeled as F) and the U.S. Army Missile Command (MICOM and labeled as M).

## Overview

Images obtained using a circular polariscope revealed that the residual stresses were localized in a region very close to the free boundary. Tests conducted with a plane polariscope, calibrated to determine the maximum principal stress direction, showed the boundary stress to be compressive. The magnitude of the stress at the surface is given by

$$\sigma_1 - \sigma_2 = \frac{R\, f_\sigma}{t} \quad . \tag{1}$$

In eq. 1, $\sigma_1 = 0$, $\sigma_2$ is the compressive residual stress, R is the isochromatic fringe number at the boundary, $f_\sigma$ is the material fringe value, and t is the thickness. Stress separation can be accomplished for points below the surface using stress separation methods [9].

Typical Results and Observations

Figure 1 shows the images of specimens recorded using a light field circular polariscope. The specimens were grown at two different times using the same SLA machine. The residual stresses depend upon the build direction. The magnitudes of the stresses were comparable for specimens built at different times, but the quality of the specimens was slightly different; several air bubbles were entrapped in the specimens on the left. Since many parts were built between the time that the two sets of specimens were fabricated, a considerable amount of the resin was replenished. This may cause differences in the material properties, including a change in the material fringe value.

Figures 2 and 3 show comparisons between specimens secured from three different sources. For specimens built in a given direction, the distribution of the residual stresses were comparable but the magnitudes were different. The supports used to hold the specimens provided by MICOM and AIDTduring the build were different from those used to fabricate the Fastec models. These differences, caused by the software used to produce the supports, did not seem to significantly affect the residual stresses.

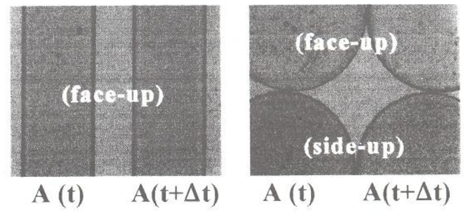


**Figure 1**. Specimens grown by AIDT using the same machine at different times.

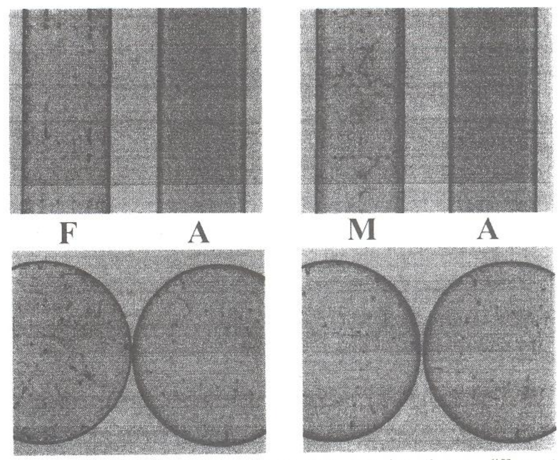


**Figure 2**. Specimens grown face-up by three different manufacturers.

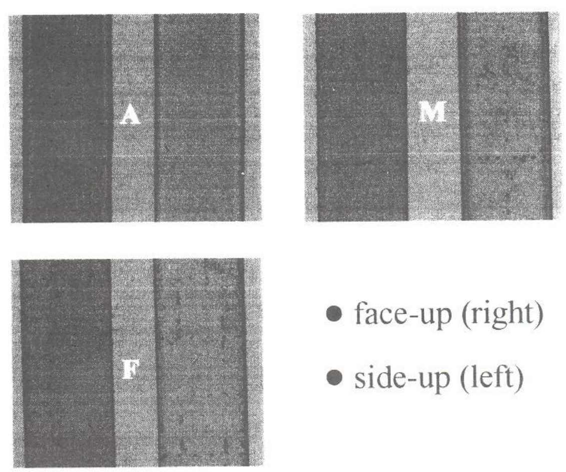


**Figure 3**. Specimens grown face-up and side-up by three different manufacturers.

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