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Modelling of the mechanical behaviour of the photopolymerization processes of resins intended for additive manufacturing (AMT) using laser-stereolithography: The influence on part quality

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Abstract

This study presents a simplified model of the polymerization process of photo-cured epoxy resin, with the aim of finding theoretical values for the mechanical properties of the material in its transition stage from liquid to solid state, approximating these properties to a single figure at the instant of its gelation in the time denominated as tg. By evaluating a phenomenon observed during the fabrication of samples using a stereolithography additive manufacturing printer, it is hoped to fit a model that will replicate the mechanical forces undergone by the manufactured part. The introduction of new hypotheses to simplify the case under study will be tested by simulating these cases using the finite element method, taking the values obtained from previous publications that used experimental and analytical analysis so that the congruence of the results will be constant throughout the model. Finding these theoretical values will help develop future criteria for the feasibility of manufacturing the parts using laser stereolithography and therefore have a direct influence on the quality of the end part.

1. Study aim

We are aware that the rise in production using SLA printers has proportionally led to the need to find a simple method to allow the user to know the feasibility of manufacturing the end part, and should it not be feasible, to reconsider the design and apply corrective factors to the thickness and reduce critical stress situations as already shown in previous publications Stava et al.

Therefore, we propose **a model that simplifies the epoxy resin polymerization photoelastic process** and the dependency on the time slope of the mechanical properties of the material to be used in the simulation (E(dt), ν(dt))[7] for a **constant value of these properties in its gelation state (E(tg), ν(tg)),** the point at which we suggest the material reaches a critical situation (breaking strain).

Phenomenon under study

By making two calibration test pieces CP01 and CP02 (Figure 1.c) printed with SLA3500 (3D Systems Inc, Rock Hill, SC 29790, USA) and Accura® 60 epoxy resin (3D Systems), to enable the team to create a database of critical situations or dimensional errors in the manufacture of the parts by SLA 'free surface', it was possible to observe a phenomenon that up to then had been recorded in the literature.

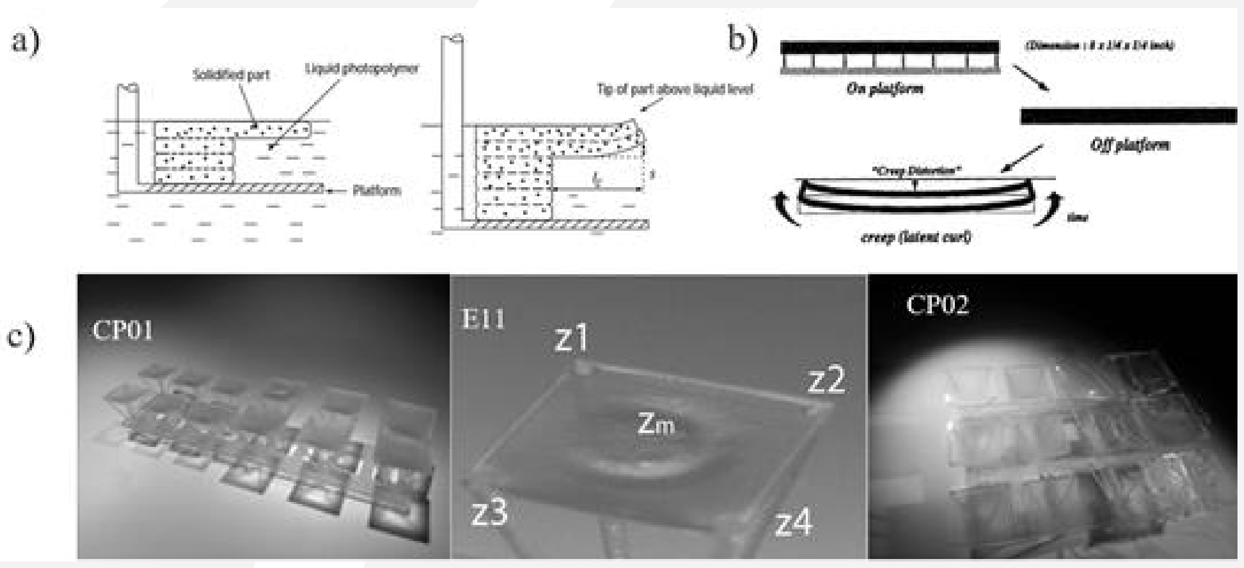
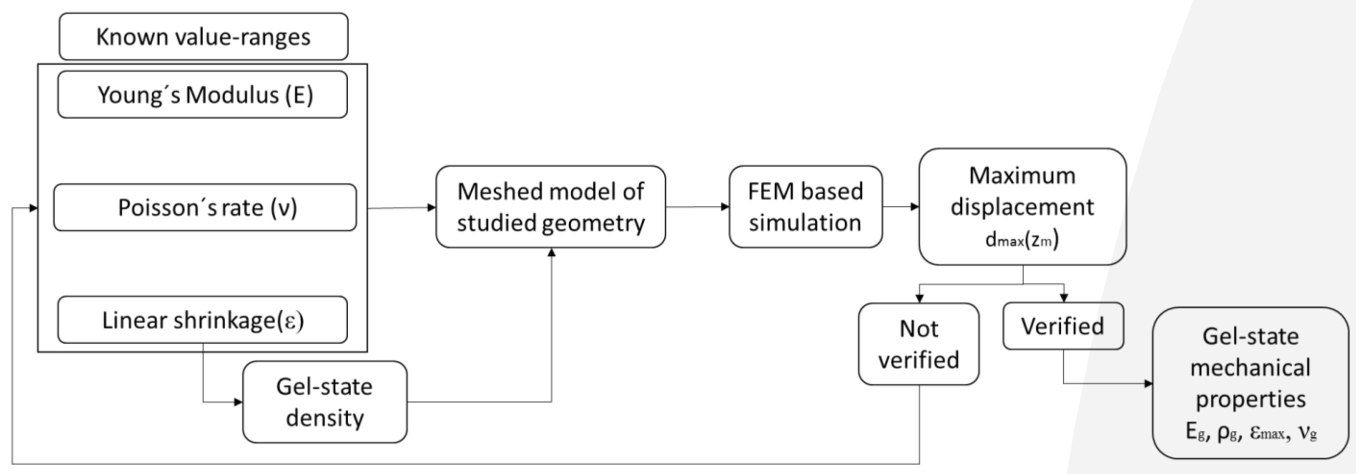


Fig. 1 a) 'Curling' effect of a cantilever beam due to creep through 'free surface' polymerization processes; b) calibration test piece and deformation observed; c) CP01/02 specimen of study and E11 testing element.

Hypothesis and process simulation

Taking an in-depth review of the literature as the basis, the factors that will influence the process giving rise to this deformation can be defined: a) maximum linear creep of the epoxy resin εmax; b) the volumetric action of gravity; c) surface support in the lower section due to the variation in density (Δρ= ρl- ρg); d) fixed constraints of the element due to its design.



Scheme 1 Layout of the procedure used through finite element simulation

2. Computer implementation

In order to validate the suggested model a simulation was performed on a section (12 mm x 12 mm x 0.6 mm) separated into 6 layers of 0.1 mm (Figure 2.a) representing the successive layers that the process would polymerize, each layer having a minimum of two octahedral elements (Figure 2.b) on the length of the thickness. The successive layers were modelled with a solid joint while the fixed displacements were applied to the opposite sides of the sections

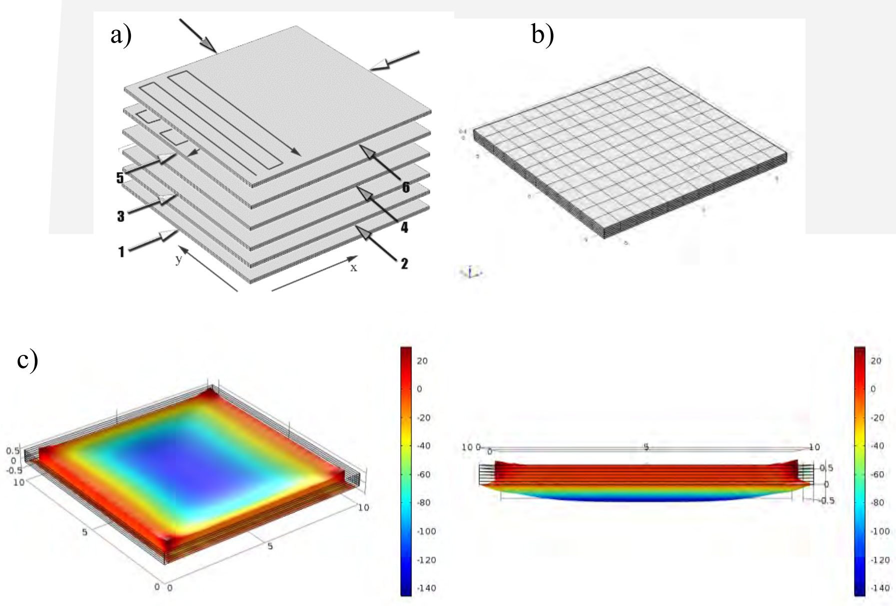


Fig. 2a) Representation of the geometric model to be studied: interspersed displacements imposed on the layers; b) symmetric meshed model for the FEA; c) deformation of the model through the action of the loads and imposed constraints

3. Results and conclusion

To evaluate the suitability of the Modulus of Elasticity in the state of gelation **Eg**, we proceed to trace a trend line for the experimental value obtained by Guees et al. for the initial elastic modulus of a just-polymerized strain of epoxy resin SL 5170 and its dependency of the time after the hatching, until 20 first minutes.

A study has been conducted that started out from an observed phenomenon. It has been possible to evaluate and model the behaviour of Accura® 60 (3D Systems) epoxy resin during the process of laser stereolithography Additive Manufacturing with an SLA 350 printer by simplifying a time-dependent case in a linear elastic stationary model.

Parameter	Value	Units
E_g	2.1	MPa
ν_g	0.3	-
ρ_g	1.17	Kg/m^3
ε_g	0.016	-
t_g	49	s

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