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Mechanical properties of 3D printed composite material

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1. Introduction

Additive manufacturing (AM), become widely used in engineering prototyping, complex geometry, and multi-purpose. The PolyJet 3D printing method is photopolymer jetting that deposits of voxel-based droplets of photopolymer resins onto a print bed, after which the resins are cured using ultraviolet (UV) lamps. The development of novel photopolymer resins, for instance, Agilus30 and Tango+ have become accessible to PolyJet technology. The mechanical flexibility of PolyJet elastomers has made them mainly useful for applications like soft robotic active hinges, actuators, and building a complex geometry [1], [2].

The paper is intended to determine the mechanical properties of Additive Manufacturing of the Digital Material DM40 (Agilus30 and VeroClear) in terms of selecting the appropriate hyperplastic model. The work aim is to compare the simulation of two hyperelastic materials Mooney-Rivlin (MR) and Ogden with the experiment. The DM40 material behavior is visco-hyperelastic, therefore the viscoelastic part of the material response will be considered.

2. Constitutive model

2.1. Hyperelastic model

The tension test was performed on a dumbbell sample under a strain rate of 4×10^{-2} s^{-1} to define the material constants.

The experimental data were used to fit the Ogden and Mooney-Rivlin models by using MSC Marc software, the strain energy function of the Ogden model is expressed by Eq.1 and data fitting, as well as the material constants, are shown in Fig.1 and Table 1 respectively [3]

$$W = \sum_{i=1}^{N} \frac{\mu_i}{\alpha_i}\left(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3\right) + \frac{K}{2}(J-1)\,, \tag{1}$$

where λ_1, λ_2, and λ_3 are principal stretches, μ_i are moduli and α_i are non-dimensional material constants. J and K are the elastic volume ratio and the material bulk modulus, respectively. The Mooney-Rivlin Strain energy function is as follows [3]

$$W = C_{10}(I_1 - 3) + C_{01}(I_2 - 3) + C_{11}(I_1 - 3)(I_1 - 3)\,, \tag{2}$$

where C_{10}, C_{01} and C_{11} are material constants while I_1 and I_2 are invariants. Fig. 2 illustrates the fitting results and the material constants are presented in Table 2.

Table 1. Ogden model constant

Terms	Moduli	Exponents
1	2.21514	0.167737
2	0.055668	5.20789
3	0.768557	0.147847

Table 2. Mooney-Rivlin model constant

Material constant	
C_{10}	0.100513
C_{01}	0.102029
C_{11}	0.0782547

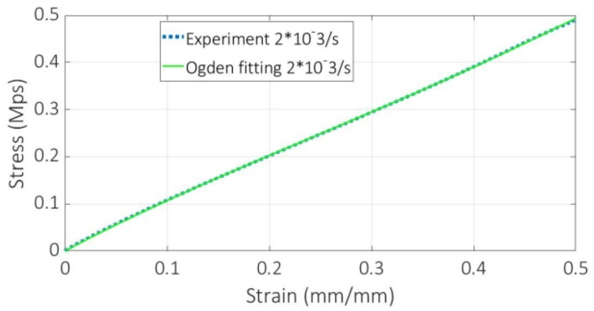

Fig. 1. Ogden model - fitting to experiment

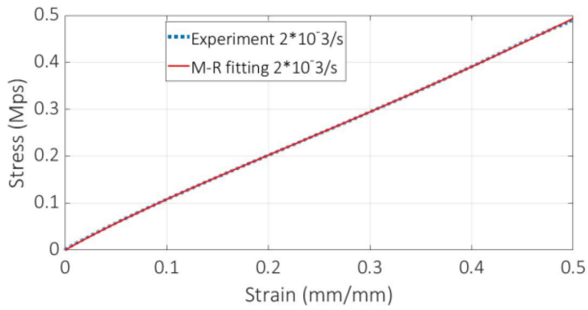

Fig. 2. MR model - fitting to experiment

2.2. Viscoelastic model

The stress relaxation was investigated on a cylindrical sample (height 25 mm and diameter 17.9 mm) at strain 0.5 with a ramp time of 1.5 s to investigate the viscoelastic properties of the material. The relaxation moduli are presented by the Prony series in Eq. (3), [3],

$$E(t) = E^{\infty} + \sum_{n=1}^{N} E^{n} \, exp(\frac{-t}{\tau_n}) \, , \tag{3}$$

where t is time, E^n is the relaxation modulus, τ_n is the relaxation time constant, and E^{∞} is the long-term modulus. The relaxation data fitted with the Prony series is in Fig. 3 and the four terms of viscoelastic material constants are presented in Table 3.

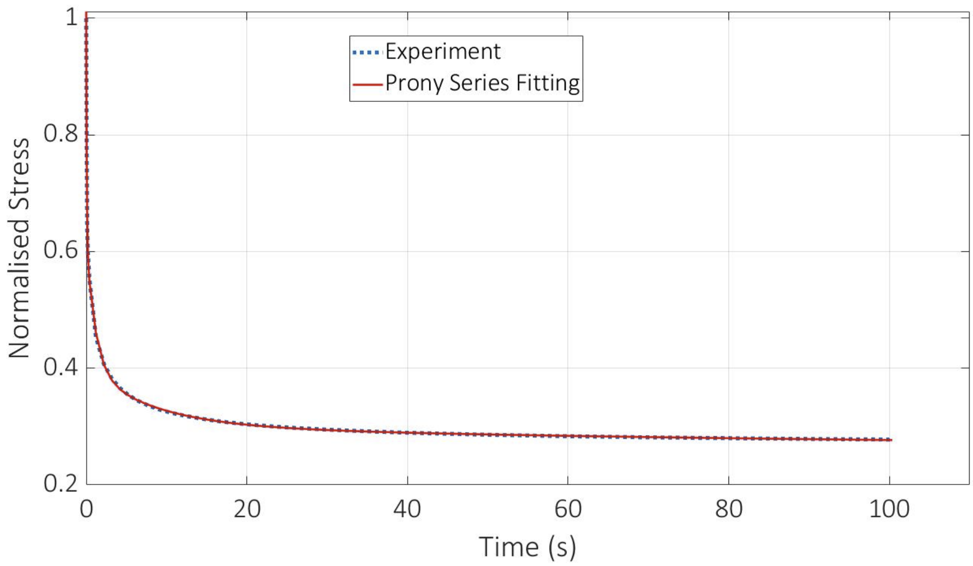

Fig. 3. The experimental fitting of the Prony series

3. Results and discussion

The hyper-viscoelastic material was validated using the cylinder sample compressed to 50 % with a strain rate of 4×10^{-2} s^{-1}. In this work, the friction between the compression plates

Table 3. Viscoelastic Prony series constant

Terms	Relaxation time	Relaxation coefficient
1	0.0657	0.38702
2	1.11	0.21787
3	8.238	0.0968119
4	100.029	0.0387605

and the sample was measured using a tribometer and considered for the simulation. The friction coefficient is μ = 0.8. It is clearly shown from the results that the Ogden model has a good agreement with the experiment data, whereas the Mooney-Rivlin has a high deviation from the experiment. This indicates that for the description of mechanical properties of the composite material DM40 (Agilus30 and VeroClear) the Ogden model with three terms can be a suitable choice.

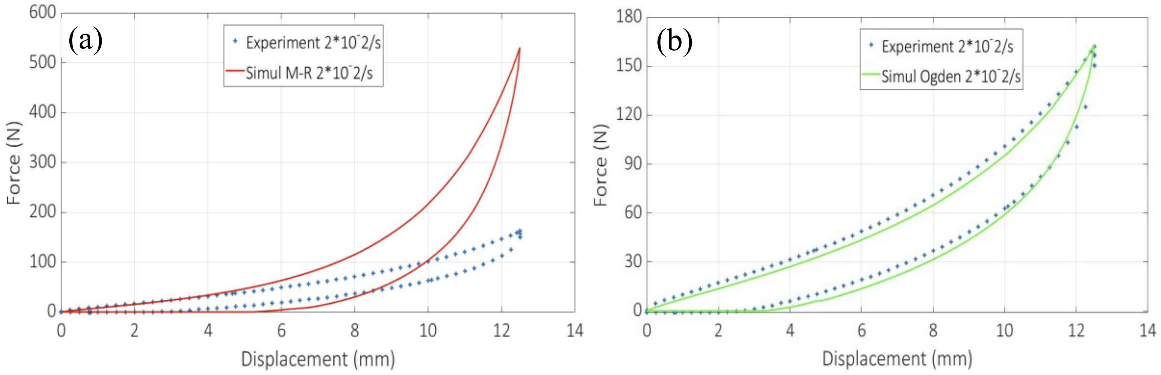

Fig. 4. The experiment validation with (a) Mooney-Rivlin and (b) Ogden models

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