Experimental study, phenomenological and adaptive neuron analysis of creep property of *Momordica augustisepala* L nanofiber reinforced polyvinyl alcohol polymer film composite

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Abstract

The viscoelastic property of packaging material affects foods’ postharvest management and biophysical quality preservation of food. This study investigated the creep viscoelastic property of neat polyvinyl alcohol film and polyvinyl alcohol film reinforced *Momordica augustisepala* nanofiber composite. The applicability and comparison of Burger phenomenological and Adaptive neuron model to analyze the creep data were investigated. The instantaneous modulus and creeping speed of neat and reinforced polyvinyl alcohol were 7.53710 MPa, 10.27580 MPa and 3.00590 MPa.s, 2.85391 MPa.s, respectively. The coefficient of determination of Burger model prediction was 0.99889 and 0.99972 for neat and composite polyvinyl alcohol film, while the coefficient of determination of Adaptive neuron model was 0.99986 for both neat and reinforced polyvinyl alcohol film. The *Momordica augustisepala* nanofiber improved the creep viscoelastic property of polyvinyl alcohol film and Adaptive neuron model showed superiority over Burger model in prediction of experimental data. The results are vita in material design, life prediction and usage prescription.

**Keywords:** *Momordica augustisepala*, viscoelastic property, polyvinyl alcohol film, adaptive neuron

1 Introduction

Postharvest or post processed handling of foods and fruits contributes to the physical quality and acceptability of the product. The biophysical quality and hygiene of food products can be
preserved or protected using active packaging material that can withstand mechanical abuse during display, packing, shelving, transportation and storage; and creation of barrier resistance for the packed food product. For a packaging material to be this active, the investigation and understanding of its behavior necessitates not only the static responses but also the time dependent or viscoelastic response, because knowledge of viscoelastic properties of foods and agricultural materials are important when considering harvesting and post harvesting processes [1]. In addition, the data on viscoelastic properties are a basic requirement as input for mathematical models that describe and predict the internal stresses and cracking during different post harvesting processes.

Mathematical and phenomenological or physical model exist for the analysis, understanding of the structure, evaluation and forecasting of viscoelastic (creep and relaxation) data. The phenomenological models are particularly useful because a larger number of rheological parameters could be estimated from creep data and elastic, while viscoelastic and viscous flow characteristics can be predicted separately [2]. Mathematical model like Findley power law is also important in this regard. However, power law analysis shows not much detail as phenomenological model does and power law shows deficiency when the effect of temperature changes is introduced. The Burger phenomenological model is represented in Figure 1 with its four elements for the creep analysis and modeling. It is a systematic combination of springs and dash pots to mimic or analyze both elastic and viscous responses of a typical material.

Figure 1. Burger model [3]
In a typical creep compliance experiment, samples are loaded with constant stress in linear material deformation region and deformation or strain is measured with respect to time. The creep compliance is the ratio of strain to stress or the inverse of Young Modulus. Burger model for creep investigation is the connection of Maxwell unit and a Kelvin unit in series and the model separates the creep strain into the instantaneous deformation (Maxwell spring), viscoelastic deformation (Kelvin unit), and the viscous deformation (Maxwell dash-pot) [4]. The Burger model equation is depicted in equation 1.

\[
\varepsilon = \frac{\sigma}{E_1} + \frac{\sigma}{E_2} \left[ 1 - \exp \left( -\frac{tE_2}{\eta_2} \right) \right] + \frac{\sigma}{\eta_1} t
\]

where \(E_1\) and \(E_2\) are elastic moduli, \(\eta_2\) and \(\eta_1\) are viscosities, \(\sigma\) is the imposed stress and \(t\) is the creep time. This model has only one retardation time, \(\tau_2 = \eta_2/E_2\) which is the time required to generate 63.2% deformation in the Kelvin unit [4] or the creeping speed.

Adaptive network based fuzzy inference system (ANFIS) is a soft computing or machine-learning methods which has the capability to understand the dynamics of experimental data and creation of accurate models for simulation and control. It is the fusion between the neural network and the fuzzy inference system, characterized by transparency of fuzzy systems and learning ability as neural networks [5]. It is based on Takagi-Sugeno fuzzy and it uses a hybrid learning algorithm. The ANFIS has layers which can be called inputs, if part, rules and normalization, then part and output [6]. A typical structure of ANFIS is represented in Figure 2, which is composed of 6 layers.

![Figure 2. Equivalent of ANFIS structure [7]](image)

The two inputs (\(x, y\)) of the system are presented (ANFIS supports multiple input, single output systems). Square nodes (adaptive nodes) show that parameters in these nodes are adjustable, to
be learned, while the circle nodes (fixed nodes) demonstrate that they are fixed parameters. A common rule set with two fuzzy if-then rules is as follows:

Rule 1: If x is $A_1$ and y is $B_1$, then $ff_1 = pp_1x + qq_1y + rr_1$  

Rule 2: If x is $A_2$ and y is $B_2$, then $ff_2 = pp_2x + qq_2y + rr_2$  

Where A, B are linguistic terms that are user-defined and representing a range of values. The sequence and functions of the layers are as follow: Layer 1: Square node equipped with node function $O_i = \mu_{A}(x)$  

Assuming x and y are the two typical input values fed at the two input nodes, which then transform those values to the membership functions (triangle, generalized bell-shaped, Gaussian membership). $O_i$ is the membership function of $A_i$ and x is the input parameter to the node. $A_i$ is the linguistic label connected with the node function.

Layer 2: This node multiplies the incoming signal and sends the product out. Each node output is the firing strength of a rule.

$w_i = (x) \times (y), i=1,2$  

Layer 3: circle node. Node computes the ratio of $i$-th rule’s firing strength to the sum of all rules’ firing strengths:

$w' = w_i / w_1 + w_2, i = 1, 2$  

Layer 4: Square node with node function:

$O_i^4 = w'_i f_i = w'_i (p_i x + q_i y + r_i)$  

p, q, r – parameter set (consequent, linear, parameters)

Layer 5: circle node. This node computes the overall output as summation of all incoming signals.

$O^5 = \text{overall output} = \sum_i w'_i f_i = \sum_i w_i f_i / \sum_i w_i$  

In the present day, the applicability of active packaging material to food and postharvest materials keeps growing. Polymers are functionalized with suitable reinforcement or fillers to create material that will not only protect the physical properties of the wrapped or sealed food products but also keeps its biological qualities. Fillers or reinforcements are capable of creation of quality barrier against oxygen and water vapor, which can affect the food quality, improvement of mechanical resistance, tearing, bursting and moisture absorption of polymer
material. Polyvinyl alcohol (PVA) is a class of thermoplastic polymer with moderate strength and high barrier resistance property. It is highly soluble in water and completely biodegradable when disposed. The objectives of this study are to investigate the effect of *Momordica augustisepala* nanofiber reinforcement on the creep property of polyvinyl alcohol film using Burger Phenomenological or physical model and to compare the Burger model efficiency with Adaptive Neuron system model.

2 Materials and Methods

2.1 Materials

The materials used include alkalized *Momordica augustisepala* L fiber, sulphuric acid, acetic acid, polyvinyl alcohol; weighing balance (0.0000 g) was used for fiber measurements. Matlab 2010 b and Microsoft excel 2010 software were used for data analysis.

2.2 Sample Development

*Momordica augustisepala* fiber was processed in accordance with the method of Adeyi *et al.* [9]. Nanoscale fiber was further extracted using the method of Nascimento *et al.* [10]. Two creep samples, neat polyvinyl alcohol film and 3 % volume fraction reinforced polyvinyl alcohol film, were prepared by surface casting to test the effect of the nanofiber on the viscoelastic property of polyvinyl alcohol film.

2.3 Sample Characterization

Dynamic Mechanical Analysis (DMA) 242E machine was used to study the creep property of the samples. Each sample was loaded with a constant stress of 5 MPa for 30 min at room temperature and strain data were collated. Nonlinear fitting in Microsoft excel was used to establish the rheological parameter and prediction according to Burger model while Matlab 2010b was used for development of Adaptive neuro fuzzy artificial intelligent model.
3 Results and Discussion

3.1 Burger Model and Prediction

The summary of the data used in this study is given in Table 1.

Table 1. Summary of creep experimental data

| Statistical Parameter | Time (min) | % strain of Neat PVA | % strain of Reinforced PVA |
|-----------------------|------------|----------------------|---------------------------|
| Min                   | 0.8460     | 0.6721               | 0.4939                    |
| Max                   | 28.9091    | 1.0363               | 0.8460                    |
| Standard Deviation    | 8.3819     | 0.0814               | 0.0864                    |

The result of the creep test carried out on neat polyvinyl alcohol and reinforced polyvinyl alcohol film is represented in Figure 3.

Figure 3. Experimental creep data of neat and reinforced PVA

It can be observed from the figure that the two samples passed through instantaneous deformation, primary, secondary and tertiary creep without rupture due to the quantity of load applied and the time of load application. However, the reinforced polyvinyl alcohol shows more resistance to creeping compared to the neat polyvinyl alcohol film.

The rheological parameters established according to Burger mode is summarized in Table 2.

Table 2. Summary of rheological parameter of both neat and reinforced PVA

| Sample          | $E_1$ (MPa) | $E_2$ (MPa) | $\eta_2$ (MPa.s) | $\eta_1$ (MPa.s) | $\tau_2$ (s) |
|-----------------|-------------|-------------|------------------|------------------|--------------|
| Neat PVA film   | 7.5371      | 16.5781     | 1915.3102        | 48.8437          | 2.85391      |
| Reinforced PVA  | 10.2758     | 18.2734     | 1711.3935        | 52.1502          | 3.00590      |
| film            |             |             |                  |                  |              |
The table shows that nanofiber reinforcement improved the property of the PVA film. For instance, the stiffness value of reinforced PVA in the elastic (EI) and transition (E2) region is greater than that of neat PVA. The viscous term (ηf) in the PVA is also smaller than the viscous term in the reinforced PVA; this means a lower viscous flow in reinforced PVA and shows ability to better resist time dependent deformation than neat PVA. Furthermore, the transition region of neat film is shorter than the transition region of reinforced film judging from the value of η2, which means that the reinforced PVA sample did not lose elastic property easily as neat PVA film did. Finally, with the value of τ2, it is obvious that neat PVA film sample creeps faster than reinforced PVA film. The overall result shows that reinforced PVA film has improved rheological properties. The result here conforms to the result of Plaseied and Fatemi [10] in the study of tensile creep and deformation modeling of vinyl ester polymer and its nanocomposite.

The prediction of Burger model is represented in Figure 4.

![Figure 4. Comparison of experimental and Burger model predicted data](image)

The figure shows that Burger model has capability to predict the experimental data with high accuracy. The coefficient of determination (R^2) for neat PVA creep response is 0.99889, while the coefficient of determination (R^2) of reinforced PVA is 0.99972.

3.2 ANFIS model and Prediction

In this study, the effect of membership function type on speed of error convergence or simulation was initially determined. The indicator for speed of error convergence was the epoch number.
The minimum epoch number is also important to prediction speed and computer memory allocation. Therefore, the membership function with minimum epoch number represents the optimum ANFIS structure. Several trials with constant four membership functions were done to search for the optimum membership function type. Figure 5 represents some of the membership functions tried.

**Figure 5.** Effect of membership function type (a) gaussmf (b) trimf (c) gbellmf (d) gauss2mf (e) pimf and (g) dsigmf on the speed of error convergence or simulation
It could be observed from Figure 5 that gbell membership function type has the highest speed of error convergence or simulation with forty epoch number. The closest to gbell membership function is the dsig membership function, which converged at sixty epoch number. Tri membership function did not show any sign of convergence even after the exhaustion of the allocated forty epoch number. Gauss2 and gauss membership functions converged at ninety and about ninety three epoch number, respectively. The Pi membership function converged at about ninety four epoch number after initial upsurge between fifty-five to sixty-five epoch number. Therefore, gbell membership function represents the optimum membership function for the development of ANFIS model structure.

The gbell input membership function and output membership function are represented in Figures 6 (a) and (b). The membership function is a fuzzy reasoning parameter used in data approximation and prediction. During the course of modeling and prediction, the membership function is expected to undergo some refinement for optimum data prediction as a result of adaptiveness of ANFIS.

Furthermore, comparing the input and optimized output membership function; it could be observed that the crossing point for the membership function line cross jumped from 0.50 y-axis to 0.80, 0.75 and 0.65 y-axis, respectively. The correlation coefficient signifies the prediction efficiency. Correlation coefficient is the square root of coefficient of determination and statistically, the closer the value of correlation coefficient to unity, the better the prediction.
Figure 7 depicts the correlation coefficient of the developed ANFIS structure and from the figure, the correlation coefficient is 0.99993; therefore, square of correlation coefficient is 0.99986 which is the coefficient of determination of ANFIS prediction. Comparing the two applied models, it is established that ANFIS performed better than Burger model. ANFIS has been previously used as a reliable tool for modelling and prediction of powder/water extraction process behaviour [11].

Figure 7. Regression plot of the ANFIS

In addition, the ANFIS generated rules for the modeling purpose is represented in Figure 8. The figure shows that 16 fuzzy rules were used for the modeling and prediction. The fewer number of rules could be related to the observed speed of the gbell membership function over the other tested membership function.
The qualitative representation of the prediction is represented in Figure 9. It could be observed that ANFIS had superiority in modeling and prediction of the experimental data. The ability of ANFIS to model and predict the experimental data for neat and reinforced PVA together at once also show robustness in its operation as seen in Figure 9 over Burger model that models the experimental data for each sample separately.

Figure 8. ANFIS generated rules

Figure 9. Prediction efficiency of ANFIS and data relationship
4.0 Conclusion
The results obtained in this study enable the following vital conclusions; that *Momordica augustisepala* L natural fiber improved the creep property of polyvinyl alcohol film, Burger model is adequate in determining the rheological parameters of the investigated samples and Adaptive neuron fuzzy has higher prediction efficiency than Burger model. Therefore, Adaptive neuron model is recommended for the life performance prediction of the investigated samples.

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