Polymer Bulletin 1, 865–869 (1979)

Polymer Bulletin

On the Concentration Dependence of the Elasticity Modulus of Soybean Globulin Gels

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Summary

The concentration dependence of the elasticity modulus (G) of gels produced by heating soybean globulins (SBG) has been investigated in the concentration range C = 7.5 - 58.4%. The tests included constant rate loading and stress relaxation. The experimental results are presented in the form of a modulus reduction parameter $b(C)=G(C) / G(C^\circ)$, where $C^\circ=15\%$ corresponds to the standard reference state. Whatever the testing conditions, the results are described by a single smooth curve similar, to a constant factor, to the concentration dependence of the equilibrium elasticity modulus of SBG gels. The experimental relationship b (C) agrees with the theoretical concentration dependence of the equilibrium polymer gel modulus according to Hermanns if it is assumed that the gel-point of SBG, $C_0 = 6.6\ \%$. Within an order of magnitude this value of C_0 is consistent with the experimental data.

Introduction

Within a relatively narrow concentration range, the concentration dependence of the elasticity modulus G (C) of biopolymer gels is usually approximated by an exponential function of the form (HIRAI, 1955):

$$G\ (C) \propto C^n, \qquad n=\text{const.} \qquad (1)$$

In most cases n=2, when C = 10 - 20% which is in good agreement with the predications of the various modifications of the theory (FERRY, 1948) which regards the process of gel formation as a result of a random polyfunctional association of Gaussian chains. However, in the case of SBG gels n=5 in the concentration range in question (BIKBOW et al., 1979a). In order to find out the reasons of such abnormality, it was thought interesting to investigate the G(C) relation for SBG gels in a broader range concentration.

Experimental

The SBG (protein - 95.3%, lipides - 0,5%, ash content- 4.2%, solubility in water 99%) were prepared by a conventional procedure (ROBBINS et al., 1966) from defatted soya flour "Soya-Fluff 200W" kindly provided by the Central Soya Intern., Inc.

The SBG solutions with C=7.5 - 20% were prepared by mixing of the dry protein preparation and water (the so-called "direct" method), and the solutions with C= 20-58.4% were prepared by back osmosis through a membrane (BRYAN et al., 1975) or without it*("reversed" methods 1 and 2, respectively). The gels were obtained by heating SBG solutions in sealed forms at 100°C for a period of 30 minutes. These conditions were optimal for given SBG preparation.

The linear region shear modulus of the gels were measured by means of a TM - SM - L dynamometer (INSTRON) using the spherical indenter penetration method (BIKBOW et al., 1979b) under constant rate loading ($C<20\%$) and stress relaxation ($C \geqslant 10\%$) at 20,0 ± 0,1°C. In the constant rate (0.05 cm/ min) loading tests the initial modulus G_0 was determinad from the slope of the initial linear portion of the load versus (penetration depth)^{1,5}curve.In the stress relaxation tests the

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*This latter variant of back osmosis method is based on the principle of limited thermodinamical compatibility of SBG and arabicum gum (ANTONOW et al., 1979).

initial penetration (0.1 cm) was effected at a rate of 0.5 cm/min. The values of relaxation modulus were determinated in the time range of from 0.2 to 60 min. The modulus determination error in both test modes did not exceed ±7%, provided that no less than three identical samples were subjected to the same test. For gels with $C \leqslant 10\%$, the sample and indenter diameters were 8.0 and 4.08, and for gels with $C \geqslant 10\%$,2.0 cm and 0.55 cm, respectively.

Results and Discussion

In the logarithmic scale the relaxation curves of gels with $C \geqslant 10\%$ may be superposed by shifting along the lg G axis (BIKBOW et al., 1979c). This fact suggests that in this case:

$$G(C,t) = f(C) \cdot \varphi(t) \tag{2}$$

where t is current time of relaxation. Since by definition

$$\lim_{t \to \infty} \varphi(t) = 1 \tag{3}$$

and

$$\lim_{t \to \infty} G(C,t) = G_{\infty}(C) \tag{4}$$

where $G_{\infty}(C)$ is the equilibrium modulus, then

$$f(C) = G_{\infty}(C). \tag{5}$$

In this case, the modulus reduction parameter is:

$$b(C)=G(C,t)/G(C^{o},t)=f(C)/f(C^{o})=G_{\infty}(C)/G_{\infty}(C^{o}), \tag{6}$$

where $C^{o} = 15\%$ corresponds to the standard reference state. Thus, to the accurancy of a constant factor, the concentration dependence of the reduction parameter is identical with that of the equilibrium modulus of gels. From (2) one concludes:

$$G_{o} \propto f_{o}(C). \tag{7}$$

Therefore, the parameter b(C) may be determined from the experimental data obtained in the constant rate loading tests as:

$$b(C) = G_{o}(C)/G_{o}(C^{o}) = f_{o}(C)/f_{o}(C^{o}). \tag{8}$$

This circumstance may be useful for comparing the experimental data obtained from different tests procedures (Fig. 1.).

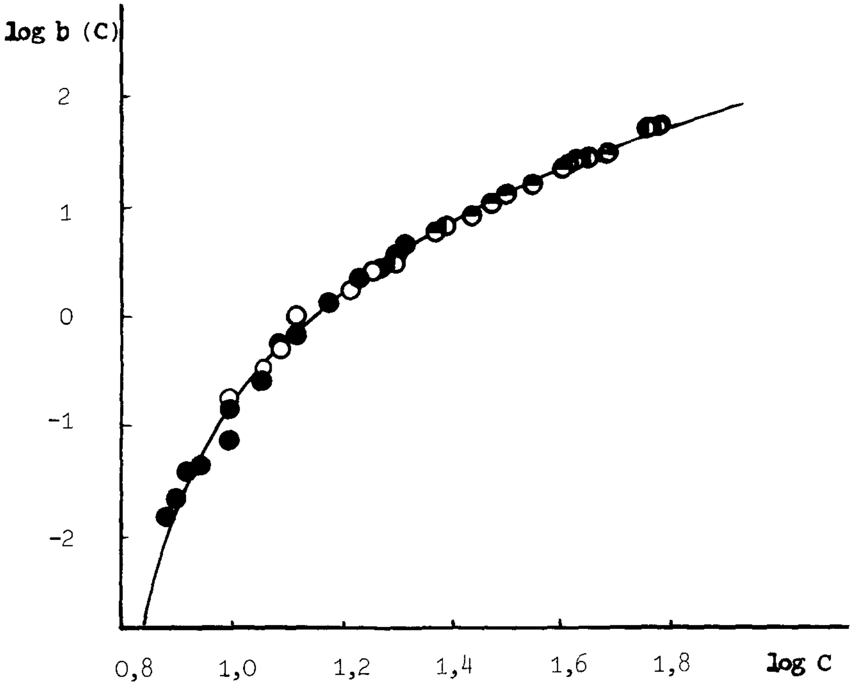

Figure 1; The concentration dependence of the reduction parameter of SBG gels (● -"direct" method, constant rate loading; ○ -"direct" method, stress relaxation; ◐ -"reversed" method 1, stress relaxation; ◓ - "reversed" method 2, stress relaxation; —— - the theoretical relationship obtained by Hermanns (HERMANNS, 1965).

Despite the different sample preparation and testing procedures, all the determined values of the parameter b(C) are described by one smooth curve. Within the experimental error this curve practically coincides with the theoretical $G_{\infty}(C)$ curve (HERMANNS, 1965) which gives a rather probable gel-point concentration

C_o=6,6%*. These results seem to account for the abnormally high value of the parameter n for SBG gels in the range C = 10 - 20%. This speculiarity is due to the fact that the C_o of SBG gels is about one order of magnitude greater than C_o of other biopolymer gels (HIRAI, 1955). Hence it may be concluded that the elasticity moduli of the gels of different biopolymers may be correctly compared only if the reduced concentrations C/C_o are equal, i.e. if gels are concidered in their corresponding states.

We have to thank the European Branch Director of Central Soya Intern., Inc., Mr.J.F.Casey for kindly providing us defatted soya flour.

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*By definition, G(C) = 0 when $0 \leqslant C \leqslant C_o$

Received September 1o, 1979