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Original Article

Physico-Mechanical Analysis of Free Ethylcellulose Films Plasticized with Incremental Weight Percents of Dibutyl Sebacate

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Abstract

This research was conducted to investigate the physico-mechanical characteristics of the ethylcellulose-based coating membranes plasticized with different weight percents of dibutyl sebacate. In this experiment, free thin polymer sheetings of the sample formulations, by incorporating incremental weight percents of the plasticizer, were prepared employing a revised casting method of delayed solvent evaporation, whereby similar flat specimens of standard dimensions were subjected to tensile loadings and extensions. The data were analyzed to fairly decide on a moderate concentration of the plasticizer to provide a rationale explanation of a strong, hard, and tough structure among the specimens. The data revealed that 40% (w/w) of the ester results in the toughest structure amongst the similar specimens of the series leading to an ultimate toughness of 3.31 mj/m^3.

Keywords: Dibutyl sebacate; Ethylcellulose; Free film; Plasticizer.
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1. Introduction

Ethyl cellulose (EC) is reportedly one of the most widely-used high molecular weight compounds whose properties have recently been reviewed [1]. The cellulose ether appears as a substantially water-insoluble polymer, excessively introduced in the coating structure of solid dosage forms to provide a controlled management on the release profile of drug substances [2-4]. Nevertheless, the polymer is also capable of being incorporated into the majority of other drug delivery systems, such as matrices [5], microspheres [6], and microcapsules [7], or in combination with other cellulose derivatives [8, 9] and eudragits [10, 11].

EC, although primarily applied in organic solutions, is now available as 30% colloidal pseudolatexes. The pseudolatex includes discrete spherical particles of 0.1-0.3 μm in diameter, dispersed in an external aqueous phase [12]. Once the EC pseudolatexes are cast or sprayed onto the surface of the desired dosage forms, the dispersion is exposed to gradual water evaporation and polymer deformation. The capillarity forces and the secondary valence forces, either through hydrogen bonds or Van der Waals', are then produced between the adjacent chains to further coalesce the polymer into a

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homogeneous, transparent film [12].

The inter-molecular cohesive bonds, and in particular the polar and hydrogen bindings among the bulky glucose subunits of ethyl cellulose chains [13], result in a structure of rigid nature with extremely low deformation and flowability. These structures prevent the effective coalescence of the polymer network during the coating procedure [14] and thus when exposed to analytical or biological fluids, create an initial barrier against the diffusion which considerably restrict the permeability. The induced osmotic pressure in the internal core region of the coated dosage forms [15] where after renders the polymer to (micro)rupturing [16] and new-born cracks propagating over the entire entanglement. These cracks would, therefore, be responsible for unexpected drug release and dose dumping phenomenon in delayed release delivery systems.

As a solution to this problem, the coating temperature is usually settled on 10-20 °C above the glass-transition temperature by virtue of its potential effect to acquire the activation energies required to break down the secondary valence bonds [17]. However, when the temperature is again lowered to the values below the glass transition, the micro-Brownian motion ceases altogether and the chain conformations are frozen into retrieve the intermolecular cohesive forces of the rigid and brittle structure.

Following the previous approach, a second way to conquer the rotational barrier is to interpose an intermediate molecule between the adjacent chains to obstruct a great number of the active centers available for the polymer rigid contacts. These molecules, recalled as plasticizers, increase the free spaces between the chains to provide a higher rotational freedom of the polymer network [18, 19] which subsequently result in a decreased T_g value below the coating temperatures, and thus a superior coalescence of the colloidal particles in the pseudolatex or the polymer in the organic solutions [2, 20].

In general, pliable films of EC are usually constructed by incorporating some plasticizers of long chain esters, such as dimethyl, diethyl, and dibutyl phthalates, triethyl and tributyl citrates, dibutyl sebacate, triacetin and also butyl and glycol esters of fatty acids [21]. In the present study, the effect of different weight percents of DBS plasticization on ethyl cellulose films are evaluated to determine the most appropriate concentration in preparing the toughest formulation in EC coating.

2. Materials and methods

2.1. Materials and instrumentation

Ethylcellulose was provided by Dow Chemical Company, USA (ethoxy content, 48.8 % DS; viscosity, 100 mPs). Dibutyl sebacate was obtained from Fluka Chemie Gmbh licensed by Sigma-Aldrich Chemie Gmbh, (USA; product no. 84840; lot and filling code 447503/1, 21904034), and the organic solvent chloroform employed in the present assay was of an analytical grade and was exerted as pure and not in combination with other organic liquids to prepare the sequential polymer solutions.

The tensile properties of the polymeric films were examined by the universal testing machine of the series Z100 produced by Zwick/Roell group, Germany, and employing a 2.0 kN force transducer (load cell) and a pair of 0.5 kN pincer grips. The data were correspondingly analyzed applying the test software testXpert V8.1 (copyright © 1995-2000, Zwick Gmbh and Co.). The machine was equipped with no external strain gauges or namely extensometers and the crosshead travel monitoring or the strain measurements were typically managed based on the entire gauge length of the specimens.

2.2 Free film preparation

To prepare the free films of ethylcellulose, casting has been selected as the most

fundamental method employed in numerous literatures and the total procedure was outlined according to the general specifications of a tensile experiment. In summary, a balanced surface is first adjusted by precisely leveling a plane table in space, applying a proper bubble tube [22] followed by subsequent trials to manually modify the possible plane deviations and improve the balancing accuracy. The nominal dimensions of the specimens were also standardized according to both ASTM D882 and ISO 527-1, being equal to 10 and 150 mm for respectively the width and the length of a rectangular flat sample, with 2.5 cm left on both endings to retain a gauge length of 100 mm at the beginning of the test. In compliance with the desired shape and dimensions of the specimens and to further promote the accuracy of the test, an individual cast with an internal area of 15×30 cm^2 and 2.5 cm depth was prepared out of (float) glass to provide about 30 similar 1-cm width specimens among which 10 to 12 of the least producing variations were selected as the final results. The sample EC solutions were prepared by dissolving 3.1 g of the polymer in about 100 ml of the solvent chloroform and adding the experimental amounts of DBS in 10% increments from zero to 70% (w/w) of the polymer mass. The mixture was stirred for 1 h and left for a further 8 to 10 h to better homogenize the solution; just prior to use, the solution was again shaken for a few min. and relaxed for a while to remove the air bubbles. The mixture was then poured into the cast from a distance above the central point and the cast was immediately covered by a piece of nylon cloth to result in a remarked reduction of the solvent evaporation which proved to develop a considerably smooth appearance of the upper surface of the film with respect to the time the solvent is freely vaporizing. The cast was left motionless for about 18 to 20 h where upon it was semi-filled with cold water after the solvent was completely dried out. The collateral sides of the rectangular film were precisely separated by means of a surgical blade (code no. 11-1*a*) and then left for the water to gradually rise up the separated film from the underlying cast plane. The sheeting was dried on a blotting paper and stored at room temperature and relative humidity (23±2 °C and 50±5% RH) for about 72 h prior to test. Just before the experiment, the length of the polymeric films were divided into 25 to 30 cm width strips and the mass and dimensions of the individual specimens were

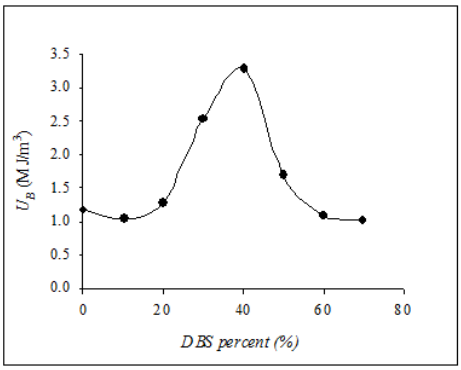

Figure 1. General variation of the strain energy stored in the film in regard to the DBS percent in the solution.

recorded to 0.1 mg and ½ mm precision, respectively. An extra piece of 2.0×0.5 cm^2 was also cut out of each film, the dimensions and the mass were similarly recorded and its average thickness was visually measured under a light microscope and a 40× objective magnification. The average area and density was then calculated for the sample according which a theoretical means was obtained to estimate the mean thickness of each strip in a series of specimens.

The tests were managed with an extension speed and acceleration of respectively, 0.5 mm/s and 0.5 mm/s^2 and the nominal stress-strain diagrams together with the registered parameters for a usual tensile experiment [23a] were recorded as σs (the stress values in N/mm^2 or MPa) for σ_y (the yield stress or the stress at the yield point), σ_{max} (the maximum tensile strength), σ_B (the stress at break), and εs (the strains or the percent elongations) for ε_y (the yield strain), and ε_B (the strain at break). The young modulus or the modulus of elasticity, E (in N/mm^2 or MPa), and the toughness modulus or the energy at break, U_B (in mj/m^3), were respectively recognized in the resilient region based on a tangent model and through the integration of the stress-strain curve from the beginning to the fracture.

3. Results and discussions

The mean values of the mechanical properties together with the standard deviations of 10 to 12 repetitions of each formulation are obtained for DBS-plasticized specimens are shown in Table 1. The maximum strength and the strength at break of the polymer construction has been revealed to be the same in tensile experiments and therefore, the maximum strength (σ_{max}), has been substituted the ultimate strength in Table 1.

In addition, to further clarify the mechanical response of the coating formulations with the plasticizer percent, the variation rate of the individual parameters with incremental concentrations of the plasticizer are found by taking the regression of the parameter values against the concentration (Table 2). As it is obvious from Table 2, the respective values of the stress, strain, and the young coefficient may follow up either a linear or exponential profile to continuously increase (the strain at break) or gradually decrease (the ultimate strength and the young modulus) by sequential addition of the plasticizer into the polymer solutions. In other words, with higher amounts of the plasticizer introduced into the organic mixture, greater numbers of DBS molecules take the possibility of contribution to the extended polymer, intervening the contact polymer-polymer forces of the adjacent chains. The entrapped molecules in EC

Table 1. Tensile values of EC films plasticized with incremental concentrations of DBS.

DBS % w/w	Thickness μm (sd)	Mass mg (sd)	E-modulus Mpa (sd)	σ_{max} MPa (sd)	ε_B % (sd)	σ_y % MPa (sd)	ε_y % (sd)	U_B mj/m^3 (sd)
0	58.0 (7.7)	88.5 (11.7)	864.26 (53.82)	38.35 (1.46)	6.83 (0.41)	38.41 (1.50)	6.83 (0.41)	1.18 (0.18)
10	56.0 (4.8)	89.0 (7.6)	770.55 (58.74)	27.84 (1.69)	7.13 (0.78)	27.81 (1.70)	6.90 (0.61)	1.04 (0.21)
20	74.2 (9.9)	104.7 (11.3)	472.20 (20.02)	16.17 (0.50)	11.48 (1.20)	14.23 (0.58)	5.91 (0.34)	1.27 (0.19)
30	72.2 (4.5)	109.4 (6.9)	374.59 (12.29)	13.05 (0.40)	25.74 (2.72)	9.88 (0.39)	5.59 (0.60)	2.53 (0.33)
40	88.9 (3.2)	127.4 (4.6)	241.71 (12.77)	9.84 (0.36)	43.59 (3.79)	7.18 (0.18)	6.27 (0.67)	3.31 (0.31)
50	81.5 (5.0)	122.9 (7.5)	113.64 (8.07)	4.27 (0.14)	45.17 (4.86)	4.13 (0.14)	8.70 (0.85)	1.69 (0.21)
60	99.3 (12.5)	133.7 (12.9)	41.59 (4.35)	2.47 (0.17)	50.29 (4.66)	2.31 (0.17)	11.29 (0.95)	1.09 (0.11)
70	122.3 (7.6)	167.9 (10.4)	25.48 (2.40)	2.11 (0.05)	55.35 (4.72)	1.87 (0.04)	15.17 (0.87)	1.02 (0.08)

Plasticizer system	σ_{max} (MPa)	σ_y (MPa)	ε_B (%)	E-modulus (MPa)
DBS	$y = -0.5754x + 33.26$ $R^2 = 0.9205^a$	-	$y = 0.8028x + 2.5992$ $R^2 = 0.9379$	$y = -11.991x + 771.02$ $R^2 = 0.9225$
	$y = 42.967e^{-0.0445x}$ $R^2 = 0.9692$	$y = 39.032e^{-0.0448x}$ $R^2 = 0.9924$	$y = 6.8617e^{0.0345x}$ $R^2 = 0.8988$	$y = 1296.1e^{-0.0524x}$ $R^2 = 0.9474$

entanglement nullify a great volume of the inter-chain cohesive forces through the new polymer-plasticizer bindings which result in a significant decline in the yield or ultimate strength and hardness of the constructed membranes. The local mobility is similarly increased in accordance to a reduction in the attractive forces of the polymer network which retains the increased percent of elongation and ease of deformation under a much lower mechanical loading. The respective values of the toughness modulus or the strain energy stored in the system are, however, attributed to the variations in both the stress and the strain of the compound and by virtue of the fact the stress is decreasing and the strain increasing, the AUC which is an integrative value of the both conjugates, first increases up to a maximum and is then continuously reduced to very low values. The increased toughness modulus, in general, provides a higher protection of the structure against the impact of the dynamic loadings [23b] and therefore the maximum area under the stress-strain diagram is generally desired among the various formulations plasticized with incremental concentrations of different plasticizers.

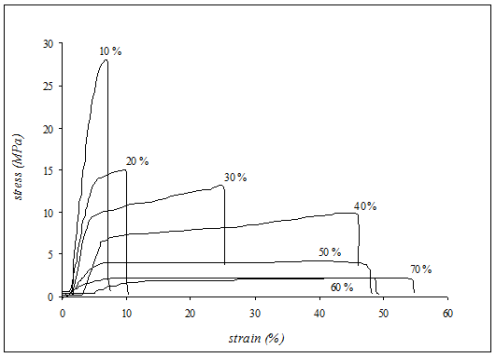

Figure 2. Average stress-strain diagrams for DBS-containing specimens concerning different plasticizer concentrations in the polymer solution.

Referring to Table 1 for subsequent values of the stress and strain, the strain is conceived to be negligible in the beginning, representing a brittle structure at plasticizer concentration less than 30%, while the polymer is rendered to considerably great deformations in the extreme mentioned limit of the plasticizer content, indicating a perfectly plastic nature of the formulation. The stress, in comparison, projects great values at plasticizer concentrations below 30% while it is continuously diminished to reduce considerably weak structures at plasticizer percents more than 50% (w/w) of the polymer solids. At a moderate concentration of 40% (w/w) of the plasticizer DBS, both the stress and the strain acquires intermediate quantities upon which the integrative energy represents a maximum in its corresponding series of specimens (Figure 1). The confirming vision of this phenomenon is established in the cumulative diagram of the average curves produced from the several repetitions of a specified formulation as illustrated in Figure 2. As it is also obvious in the compiling diagram, the EC membranes plasticized with the commercial DBS produce a rather stiff and strong structure of brittle nature at plasticizer concentrations of less than 30% whilst in concentrations more than 50% (w/w; i.e., the three end formulations) a profoundly soft and weak plastic construction is produced.

4. Conclusion

Dibutyl sebacate, commonly employed in Surelease® products, proposes a suitable

plasticizing effect in EC networks with incremental concentration of the plasticizer being responsible for the continuous reduction of the maximum strength and young modulus. The percent elongation, in comparison, reveals a continuous increase with gradual increments of the plasticizer percent and the ultimate toughness modulus which displays the area under the stress-strain curve comes into a maximum at an approximate concentration of 40% (w/w) of the plasticizer. The toughest formulation, however, denotes for the greatest resistance against the dynamic loadings and the DBS-containing systems, in consequence, project a proper resistance at 40% (w/w) of the plasticizer.

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