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PLASTICIZING EFFECT OF SUCROSE PALMITATE ON THE MECHANICAL PROPERTIES OF POLYVINYL CHLORIDE FILMS

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Abstract
Sucrose palmitate (SP70) acts as an effective plasticizer of polyvinyl chloride: at 40% content, the elongation at break increases from 7.6% to 277%, and Young's modulus decreases almost threefold (from 1443 to 509 MPa). PVC films containing 0, 10, 20, 40 and 60% sucrose palmitate were prepared by casting from tetrahydrofuran solution. The mechanical properties were determined in uniaxial tension at a crosshead speed of 100 mm/min. With increasing ester content, the modulus of elasticity and tensile strength decrease monotonically, while the elongation at break and the work to break increase, reaching a maximum at 40%. At 60%, the elongation drops to 188%, which indicates that the compatibility limit of the plasticizer with the polymer has been exceeded.

Keywords: polyvinyl chloride, sucrose esters, sucrose palmitate, plasticizer, mechanical properties, Young's modulus.

INTRODUCTION

Polyvinyl chloride (PVC) is one of the most widely used thermoplastics. In its pure form, it is hard and brittle due to the strong dipole-dipole interactions between the C–Cl groups of adjacent chains and the high glass transition temperature (about 80 °C). To obtain flexible products such as films, cable insulation, flooring, and medical devices, plasticizers are added to the polymer, often at contents exceeding 30–40%.

The action of plasticizers is explained by three classical theories [1]. According to the lubrication theory, the plasticizer molecules reduce friction between macromolecules. The gel theory considers the plasticized polymer as a three-dimensional network of weak bonds that the plasticizer continuously breaks and rebuilds. The free volume theory relates the effect to the increase in free space between the chains, which increases segmental mobility and lowers the glass transition temperature. The effectiveness of a given plasticizer depends on the balance between the polar groups in its molecule (most often ester groups), which provide compatibility with PVC, and the nonpolar aliphatic chains, which keep the macromolecules apart [1].

Historically, the most important group of PVC plasticizers has been the phthalic acid esters, especially di(2-ethylhexyl) phthalate (DEHP) [1]. Phthalates are not chemically bound to the polymer and, over time, migrate from the product into the environment, food and the human body. DEHP has been linked to asthma, bronchitis and cancer [2]. In the EU, it is classified as a reproductive toxicant, Category 1B (H360FD), under Regulation (EC) No 1272/2008 and is subject to an authorisation procedure under REACH [3]. In medical devices, Regulation (EU) 2017/745 permits such substances at concentrations above 0.1% (w/w) only with specific justification and labelling [3].

These limitations have stimulated the search for safe plasticizers from renewable raw materials, such as vegetable oils, citric

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and succinic acids, isosorbide and carbohydrates [1, 2]. For example, mixtures of succinic acid esters plasticize PVC similarly to commercial phthalates [2]. Carbohydrate esters are a promising group because they combine several ester groups with a tunable acyl chain length. Yin and Hakkarainen found that sucrose octaacetate provided the highest elongation at break among the PVC blends they studied, which indicates the potential of sugar esters as plasticizers [4].

Sucrose esters are nonionic surfactants derived from sucrose and fatty acids. The degree of esterification varies from 1 to 8 and determines their hydrophilic-lipophilic balance, while the length of the fatty chain determines their phase behavior [5]. They are biodegradable and nontoxic and are widely used in the food, cosmetic and pharmaceutical industries [5]. Their molecules combine a polar sugar head and ester groups with a long aliphatic chain, a structure similar to that of effective plasticizers [1].

The performance of sucrose esters in polymer films depends on the matrix. In hydrophilic fish gelatin films, replacing glycerol with Sucrose palmitate or sucrose stearate increases strength and Young's modulus but reduces elongation [6]. In starch–polycaprolactone blends, a sucrose ester has been used as a plasticizer for biodegradable plastics [7]. In our previous studies, a mixture of Sucrose palmitate and inulin acetate (15% in total) was shown to lower the glass transition temperature of PVC from 80.5 to 59.3 °C [8]. The aliphatic ester isobutyl caprate lowers T_g to 53.5 °C at 60% content [9]. In both cases, the single glass transition indicates good compatibility with the polymer, but the effect of Sucrose palmitate on the mechanical properties of PVC has not yet been studied.

The aim of the present work is to evaluate the plasticizing effect of Sucrose palmitate as the sole plasticizer on the mechanical properties of PVC films at contents of 10–60% and to determine its optimal concentration.

MATERIALS AND METHODS

Materials

Commercial polyvinyl chloride without colorants, stabilizers, and fillers was used. Sucrose palmitate (SP70) was tested as a plasticizer, and tetrahydrofuran (THF) was used as a solvent.

Preparing the films

PVC films with sucrose palmitate contents of 0, 10, 20, 40 and 60% were prepared by solution casting. The samples are designated PVC, DVF-6, DVF-5, DVF-9 and DVF-4, respectively.

1. The required amount of PVC was weighed on an analytical balance and placed in a 150 cm³ beaker.
2. 100 cm³ of THF was added and the mixture was heated in a water bath at 40 °C until the polymer was completely dissolved.
3. The required amount of sucrose palmitate was added and the solution was stirred with a magnetic stirrer for 2 h until fully homogenized.
4. The solution was poured into Petri dishes and left until the solvent evaporated.
5. The film was dried at room temperature in a vacuum desiccator.

Mechanical tests

Mechanical tests were carried out on a Lloyd LS1 universal testing machine in uniaxial tension at a crosshead speed of 100 mm/min and room temperature. The machine was equipped with pneumatic grips. From each film, 9–12 specimens 10 mm wide were cut with a scalpel. Their thickness was measured with a Micromaster IP54 electronic micrometer (TESA SA, Switzerland) with an accuracy of 1 μm. The film thickness ranged from 0.11 to 0.39 mm and the gauge length from 7 to 40 mm.

The built-in software of the instrument records the Young's modulus E (MPa), the breaking force F (N), the extension at break ΔL (mm), the work to break W (N·mm) and the elongation at break ε (%). The tensile strength was calculated for each specimen from the initial cross-sectional area A = b ×

h (width × thickness), and the elongation at break from the gauge length L_0:

$$\sigma_B = F_B / A,\ A = b \times h, \quad (1)$$

$$\varepsilon = \Delta L / L_0 \cdot 100, \% \quad (2)$$

Statistical processing

Only specimens with a valid fracture were included: n = 10 for neat PVC and n = 7 for each plasticized film. The results are presented as mean ± standard deviation.

RESULTS

The addition of sucrose palmitate transforms the rigid and brittle PVC into a flexible material. The unplasticized film breaks at an elongation of 7.6 ± 4.9%, while the film with 40% ester reaches 277 ± 146% (Fig. 1). The strength properties are summarized in Table 1.

Table 1. *Strength properties of PVC films (mean ± SD)*

Sample	SP70, %	n	Thickness h, mm	Breaking force F_B, N	Tensile strength σ_B, MPa	Work to break W, N·mm
PVC	0	10	0.12 ± 0.01	59.9 ± 14.0	50.6 ± 11.1	51 ± 23
DVF-6	10	7	0.21 ± 0.03	55.2 ± 12.2	25.5 ± 3.3	796 ± 385
DVF-5	20	7	0.26 ± 0.05	62.9 ± 14.6	24.4 ± 4.7	605 ± 415
DVF-9	40	7	0.24 ± 0.03	36.3 ± 5.8	15.5 ± 2.4	1829 ± 992
DVF-4	60	7	0.32 ± 0.05	27.2 ± 2.7	8.6 ± 1.1	1185 ± 724

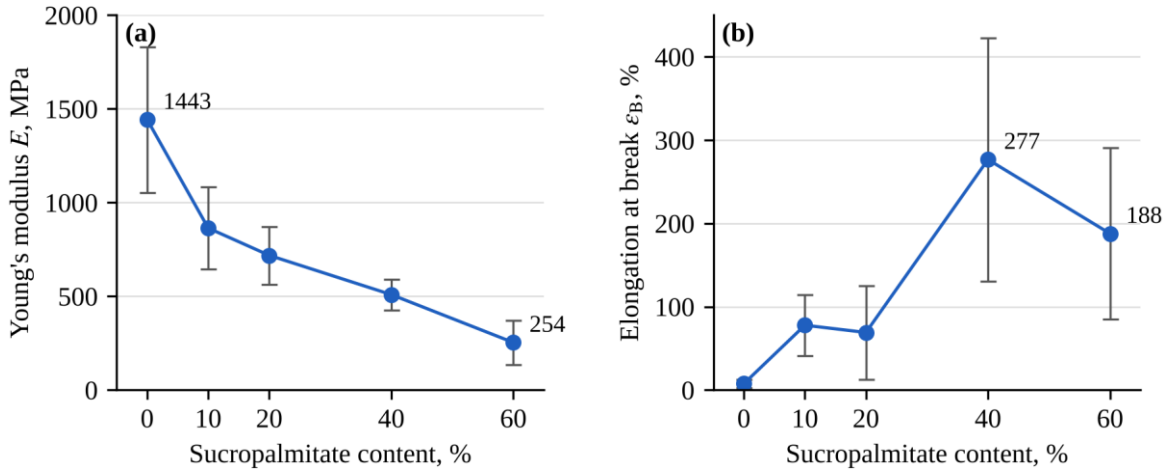


Fig. 1. *Young's modulus (a) and elongation at break (b) of PVC films as a function of sucrose palmitate content (mean ± SD, n = 7–10).*

The tensile strength decreases monotonically from 50.6 MPa for neat PVC to 8.6 MPa at 60% ester. The work to break, which characterizes the toughness of the material, increases about 36-fold at 40% sucrose palmitate and decreases at 60%.

Young's modulus decreases most sharply with the first 10% of ester (by 40%) and then decreases almost linearly to 254 MPa at 60%. The elongation at break increases stepwise: 69–78% at 10–20%, with a maximum of 277% at 40%. The scatter of elongation values for the plasticized films is large (coefficient of variation 47–81%).

DISCUSSION

The simultaneous decrease in modulus and strength and increase in elongation are typical signs of external plasticization. Sucrose palmitate molecules position themselves between the PVC chains, weaken the intermolecular dipole-dipole interactions between the C–Cl groups and increase the free volume. This increases segmental mobility and allows large plastic deformation before fracture.

The largest drop in modulus occurs with the first 10% of ester: a relatively small

addition is sufficient to disrupt part of the interchain interactions. Between 10 and 20%, the elongation remains practically unchanged (78 and 69%, within the scatter), and the breaking force stays at 55–63 N, as for neat PVC. The decrease in tensile strength in this range is therefore partly due to the greater thickness of the plasticized films (0.21–0.26 versus 0.12 mm), which results in a larger cross-section.

At 40% sucrose palmitate , the best balance of properties is obtained: maximum elongation (277%) and maximum work to break (1829 N·mm) while the tensile strength is retained at 15.5 MPa. At 60% ester, the elongation and work to break decrease (188% and 1185 N·mm), and the strength drops to 8.6 MPa. This behavior indicates that the compatibility limit of the system is exceeded: the excess ester probably forms a separate phase that acts as a defect and initiates premature fracture. Similarly, for isobutyl caprate the decrease in T_g was found to be pronounced up to 40% (to 56.7 °C), whereas above this content it levels off (53.5 °C at 60%) [9].

The large scatter of elongation at 40 and 60% is characteristic of cast films and results from non-uniform thickness and local defects. In DVF-4 the thickness varies from 0.26 to 0.39 mm. Improving film uniformity and carrying out additional studies (DSC, plasticizer migration) would help confirm the proposed mechanism.

CONCLUSION

1. Sucrose palmitate exhibits a pronounced plasticizing effect on polyvinyl chloride: as its content increases from 0 to 60%, Young's modulus decreases from 1443 to 254 MPa and tensile strength from 50.6 to 8.6 MPa.
2. The elongation at break increases from 7.6% to 277% at 40% ester, and the work to break increases approximately 36-fold.
3. The optimal sucrose palmitate content is about 40%. At 60%, elongation and toughness decrease, indicating that the compatibility limit has been exceeded.
4. Sucrose palmitate is a promising bioplasticizer for PVC and an alternative to phthalate plasticizers.

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REFERENCE

[1] Bocqué M., Voirin C., Lapinte V., Caillol S., Robin J.-J. Petro-based and bio-based plasticizers: Chemical structures to plasticizing properties. Journal of Polymer Science Part A: Polymer Chemistry, 2016, 54(1), 11–33. DOI: 10.1002/pola.27917.

[2] Ledniowska K., Nosal-Kovalenko H., Janik W., Krasuska A., Stańczyk D., Sabura E., Bartoszewicz M., Rybak A. Effective, environmentally friendly PVC plasticizers based on succinic acid. Polymers, 2022, 14(7), 1295. DOI: 10.3390/polym14071295.

[3] Notargiacomo M.-C. Phthalates in medical devices: Context and European regulatory requirements. NAMSA, 19.02.2025 (Regulation (EC) No 1272/2008; Regulation (EC) No 1907/2006; Regulation (EU) 2017/745).

[4] Yin B., Hakkarainen M. Green plasticizers from liquefied wood. Waste and Biomass Valorization, 2014, 5(4), 651–659. DOI: 10.1007/s12649-013-9259-2.

[5] Cholakova D., Tcholakova S. Sucrose ester surfactants: Current understanding and emerging perspectives. Current Opinion in Colloid & Interface Science, 2024, 73, 101832. DOI: 10.1016/j.cocis.2024.101832.

[6] Amalini A.N., Norziah M.H., Khan I., Haafiz M.K.M. Exploring the properties of modified fish gelatin films incorporated with different fatty acid sucrose esters. Food Packaging and Shelf Life, 2018, 15, 105–112. DOI: 10.1016/j.fpsl.2017.12.003.

[7] Sriroth K. et al. Sucrose ester as plasticizer for biodegradable plastic (starch–polycaprolactone blend). Proceedings of the International Society of Sugar Cane Technologists (ISSCT), 1999.

[8] Vassilev D., Petkova N., Atanasova M., Koleva M., Denev P. Application of carbohydrate esters as co-plasticizers and biodegradable additives in plastics. International Scientific Conference UNITECH'21, Gabrovo, 19–20 November 2021, 323–325.

[9] Vasilev D., Petkova N., Atanasova M., Denev P. Application of caprate aliphatic ester as bioplasticizer and bio-additive in plastics. International Scientific Conference UNITECH 2022, Gabrovo, 18–19 November 2022.