Drug Development and Industrial Pharmacy, 26(2), 205–210 (2000)

COMMUNICATION

Influence of Surfactants in Aqueous-Based Polymeric Dispersions on the Thermomechanical and Adhesive Properties of Acrylic Films

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ABSTRACT

Good adhesion between a polymeric film and the surface of a solid substrate is critical to the performance of coated pharmaceutical products. Previous research has shown that tablet wettability by an organic-based cellulosic solution could predict the extent of film-tablet adhesion. Using an aqueous-based acrylic polymeric dispersion, the current study investigated the relationship between film adhesion and tablet wettability. Up to 10% (w/w based on dry polymer weight) polysorbate 80 or sorbitan monooleate was incorporated into the film-coating formulations. While the contact angle between the polymeric dispersion and the tablet surface was dependent on the type and concentration of surfactants added to the coating formulation, no correlation between tablet wettability and polymer adhesion could be established. The addition of surfactants to formulations containing the hydrophobic plasticizer tributyl citrate (TBC) caused lowering of the glass transition temperature of the polymer. Increased force of adhesion, elongation at adhesive failure, and adhesive toughness, however, were noted only in the TBC–plasticized films containing polysorbate 80. These findings demonstrate that our understanding of the mechanisms involved in film-tablet adhesion is still quite limited.

Key Words: *Film coating; Plasticizer; Polymer adhesion; Surfactant; Tablet wettability.*

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INTRODUCTION

Good adhesion between a polymeric film and the surface of a tablet is major prerequisite for coated pharmaceutical products (1,2). Loss of adhesion may compromise the mechanical protection that the film coating provides to the solid substrate (3). An accumulation of moisture at the film-tablet interface may also occur as a result of a loss of polymer adhesion, which could significantly affect the stability of drugs susceptible to degradation by hydrolytic mechanisms (4). In addition, adhesion experiments during the preformulation stages of product development may be useful for evaluating tablet excipients and polymeric film coating formulations (5).

Previous research involving polymer adhesion has focused primarily on organic-based cellulosic films (5–7). Excipients used in tablet formulations and the compressional force employed during the tableting process have been found to influence the strength of polymer adhesion (1,8). Several studies have been published on the effects of various organic solvents used in the polymeric coating on film-tablet adhesion (6). Wood and Harder (9) used contact angle measurements, as an indication of surface wettability, to predict polymer adhesion. It is the polymer, however, that adheres to the tablet surface, not the solvent, and using tablet wettability to predict polymer adhesion may not be valid, particularly for polymeric dispersions. Film coating technology today has shifted toward aqueous-based systems for environmental and economic concerns, and many polymeric materials are currently available as dispersed systems (10). The objective of the current study was to investigate the relationship between film-tablet adhesion and tablet wettability using an aqueous-based acrylic polymeric dispersion.

MATERIALS

Tablet compacts consisted of 69% anhydrous lactose (Sheffield Products, Norwich, NY), 30% hydrogenated castor oil (Sterotex® K, Abitec Corp., Columbus, OH), 0.5% Cab-O-Sil® M-5P (Cabot Corp., Tuscola, IL) as a glidant, and 0.5% magnesium stearate (Spectrum, Gardena, CA) as a lubricating agent. Röhm America, Incorporated (Somerset, NJ) donated the aqueous dispersions of the enteric acrylic copolymer Eudragit® L 30 D-55. The plasticizers triethyl citrate (TEC) and tributyl citrate (TBC) were supplied by Morflex, Incorporated (Greensboro, NC), and Croda, Incorporated (Parsippany, NJ) donated the polysorbate 80 and sorbitan monooleate. Scotch double-coated tape 442 was supplied by 3M (St. Paul, MN).

METHODS

Preparation of Tablets

Tablets were prepared using a Stokes B2 16-station rotary tablet press (Stokes-Merrill Corp., Bristol, PA). Excipients were passed through a 40-mesh screen prior to compression. Flat-faced punches with a beveled edge were employed to compress the tablets to a hardness of 10 kg. All tablets had a diameter of 10.20 mm and a height of approximately 6.20 mm.

Coating of Tablets

The surfactant and the plasticizer were thoroughly dispersed in purified water using a rotor-stador mixer (Tekmar Company, Cincinnati, OH). The amount of plasticizer in all formulations was held constant at 20% (w/w based on dry polymer weight), while the surfactant concentration varied up to 10% (w/w based on dry polymer weight). Sufficient water was used to reduce the solids content of the final dispersions to 20%. To ensure sufficient time for plasticization of the polymer, the aqueous dispersions containing the water-soluble TEC were mixed for 30 min prior to initiation of the spraying process, while mixing times were extended to 48 hr for the formulations containing the water-insoluble TBC (11,12).

A spray atomization technique was employed to coat tablet compacts using an apparatus similar to that described by Obara and McGinity (10). Briefly, tablets were attached to a rotating drum using double-sided adhesive tape. The drum was operated at a rate of 100 rpm. From a spray gun (Badger, model 350, Franklin Park, IL), the polymeric dispersion was atomized using compressed air and sprayed onto one side of the tablet compacts. Heated dry air was supplied to the cylinder to maintain the temperature of the tablet surface at 34°C. The distance between the nozzle of the gun and the tablet surface was approximately 20 cm. For each film coating formulation, 50 g was sprayed onto the tablets. This amount of polymer produced a film thickness of approximately 100 μm. After spraying was completed, the tablets were removed and stored in a 40°C chamber for 2 hr to promote further coalescence of the polymeric film (13,14).

Determination of Adhesive Properties

Butt adhesion experiments were conducted using a Chatillon digital force gauge DFGS50 attached to a Chatillon TCD-200 motorized test stand (Chatillon Force Measurement, Greensboro, NC). A more detailed description of the apparatus has been published in previous reports (2,15,16). The film coating at the beveled edge of the tablet was carefully removed using a scalpel. The tablet was affixed to the lower, stationary platen using double-sided adhesive tape. Tape was placed on top of the tablet, and the upper platen was lowered to the tablet surface. The upper platen was raised at a constant rate of 2.5 mm/min. Force and deflection values were recorded on a computer at intervals of 10 to 20 μm, and force-deflection profiles were constructed from the data. An example of a force-deflection profile obtained from the Chatillon apparatus is shown in Fig. 1. The force required to remove the film coating from the surface of the tablet, known as the adhesive force, and the elongation at adhesive failure, equivalent to elongation at break in tensile testing of free films, were determined. The area under the force-deflection curve, known as the adhesive toughness, was calculated.

Tablet Wettability

The contact angle between the polymeric dispersions and the tablet surface was determined using a Manual Contact Angle Meter (Tantec, Schaumburg, IL). Uncoated tablets were lightly brushed to remove residual powder from the surface, then placed on the stationary platen. A 2-ml glass pipette was used to deliver the polymeric dispersions onto the tablet surfaces. The contact angles were measured within 10 sec. At least 15 measurements were made for each coating formulation.

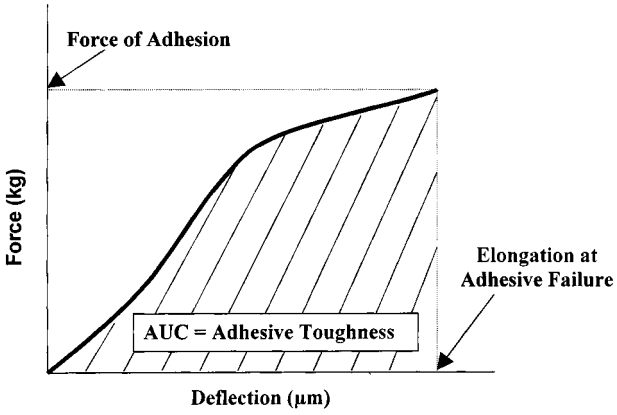

Figure 1. Example of a force-deflection profile obtained from a butt adhesion experiment using a Chatillon digital force gauge attached to a motorized test stand.

Thermal Analysis

The glass transition temperature T_g of the acrylic films was determined using a modulated differential scanning calorimeter (DSC) model DSC 2920 (TA Instruments, Houston, TX). The apparatus was calibrated using the melting transition of indium. Since an earlier study demonstrated that the hydrophobicity of the tablet core will influence the T_g of the acrylic polymer for films containing water-soluble plasticizers such as TEC (15), approximately 10 mg of the coating was removed from the tablet surface for thermal analysis. The modulating signal was set at 0.32°C per min, and the scan rate was 10°C per min from −10°C to 130°C. No previous heating or quenching was performed on the samples. The T_g was calculated as the midpoint of the endothermic curve. Three samples were tested for each formulation.

RESULTS

Previous researchers used wettability of a tablet by a polymeric solution as a tool to predict the strength of film-tablet adhesion (6,9). A polymer solution that spreads more easily across the tablet allows for more extensive interaction with the polymer chains and the formation of a greater number of bonds. Film-coating technology today, however, has shifted toward aqueous-based systems due to environmental and economic concerns (10). Many polymeric materials commercially available are formulated as dispersions in which latex particles are suspended within an aqueous system. Since it is the polymer, not the solvent, that interacts with and adheres to the tablet surface, tablet wettability by polymeric dispersions may not be a valid indicator of film-tablet adhesion.

Surfactants have been incorporated into polymeric solutions to improve the spreadability of the coating across tablet surfaces (17,18). More recently, surfactants have been employed to modulate drug release from film-coated solids (19,20). In the present study, surfactants were added to film-coating formulations to alter tablet wettability by the polymeric dispersions. Figure 2 depicts the contact angle between the tablet surface and the poly-

meric dispersions as a function of surfactant concentration. Formulations containing TBC as the plasticizer (0% surfactant) exhibited better tablet wettability than the TEC–plasticized polymeric dispersions. These results were attributed to the hydrophobicity of the tablet compact, with the coating formulation containing the hydrophobic plasticizer interacting to a greater extent with the hydrophobic surface of the tablet. Tablet wettability was decreased on the addition of sorbitan monooleate or polysorbate 80 to the TBC–plasticized coating formulations irrespective of the concentration, as demonstrated by the increased contact angle between the polymeric dispersion and the tablet surface. The incorporation of 0.1% of either surfactant into formulations containing TEC improved tablet wettability, although higher concentrations of these surfactants did not further enhance the surface wettability.

While the wettability of the tablet compacts by the polymeric dispersions was altered with the addition of surfactants to the film coatings, no significant difference in the strength of adhesion was observed for nearly all the formulations investigated irrespective of the plasticizer used, as shown in Fig. 3. The notable exception was the TBC–plasticized film containing polysorbate 80. These formulations showed an increase in the force of adhesion, the elongation at adhesive failure, and the adhesive toughness. The increased adhesive toughness suggests that the addition of polysorbate 80 produced a more highly plasticized polymer, as supported by our previous research, in which increased plasticizer concentration caused an increase in the adhesive toughness of the acrylic polymer (15).

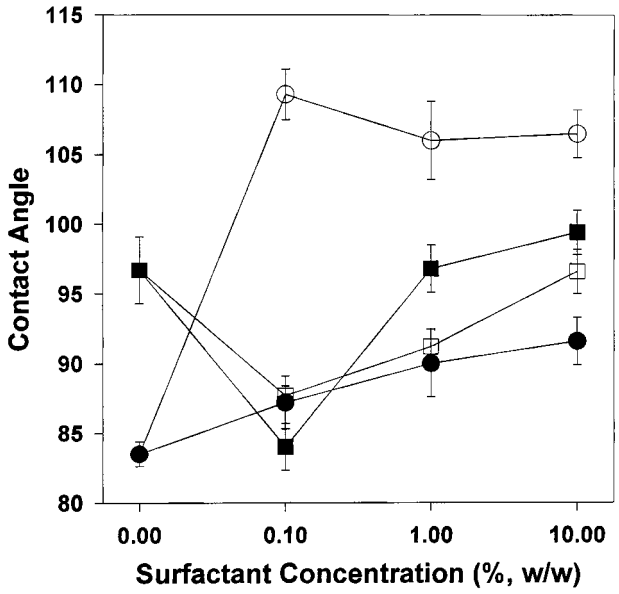

Figure 2. Contact angles between the tablet surface and the aqueous polymeric dispersions as a function of surfactant concentration ($n = 10$). ○, sorbitan monooleate/TBC; □, sorbitan monooleate/TEC; ●, polysorbate 80/TBC; ■, polysorbate 80/TEC.

To investigate further the function of surfactants in the polymeric dispersions, the glass transition temperatures T_g of the films from the coated tablets were determined; the data are presented in Fig. 4. A decrease in the T_g of the polymer was observed with increasing amounts of polysorbate 80 or sorbitan monooleate in films containing TBC as the plasticizing agent, whereas no significant change in the T_g of the TEC–plasticized acrylic films was noted. While Lindholm and coworkers (21) showed that high concentrations (up to 60%) of surfactants could plasticize ethylcellulose films, the T_g of the acrylic polymer in the present study decreased on the addition of either surfactant only in the TBC–plasticized films. These findings suggest, therefore, that the surfactants in the acrylic films emulsified the hydrophobic plasticizer, facilitating the partitioning of the plasticizer into the polymer.

Plasticizer partitioning requires dissolution of the liquid plasticizer droplets in the water phase, movement of the dissolved plasticizer molecules through the water phase to the polymer surface, and diffusion of the plasticizer molecules within the latex particles (22). The partitioning of water-soluble plasticizers into the polymer phase has been shown to occur rapidly (23), whereas extended periods of mixing are required for the uptake of water-insoluble plasticizers such as TBC into the polymer phase (11,23). Insufficient time for plasticization of the polymer may adversely affect the dissolution of coated solids as minimal disruption of the intermolecular attractions between polymer chains causes the coating to become brittle or cracked (12). Furthermore, uneven plasticizer distribution within the coating may occur as both the unincorporated plasticizer droplets and the plasticized polymer particles are sprayed onto the substrates during the coating process, potentially causing stability problems during aging (11,23). In the current study, the surfactants emulsified the hydrophobic plasticizer, enhancing the partitioning of TBC into the polymer. Furthermore, a direct relationship was found between the concentration of the surfactant and the T_g of the acrylic film, with higher concentrations of the sur-

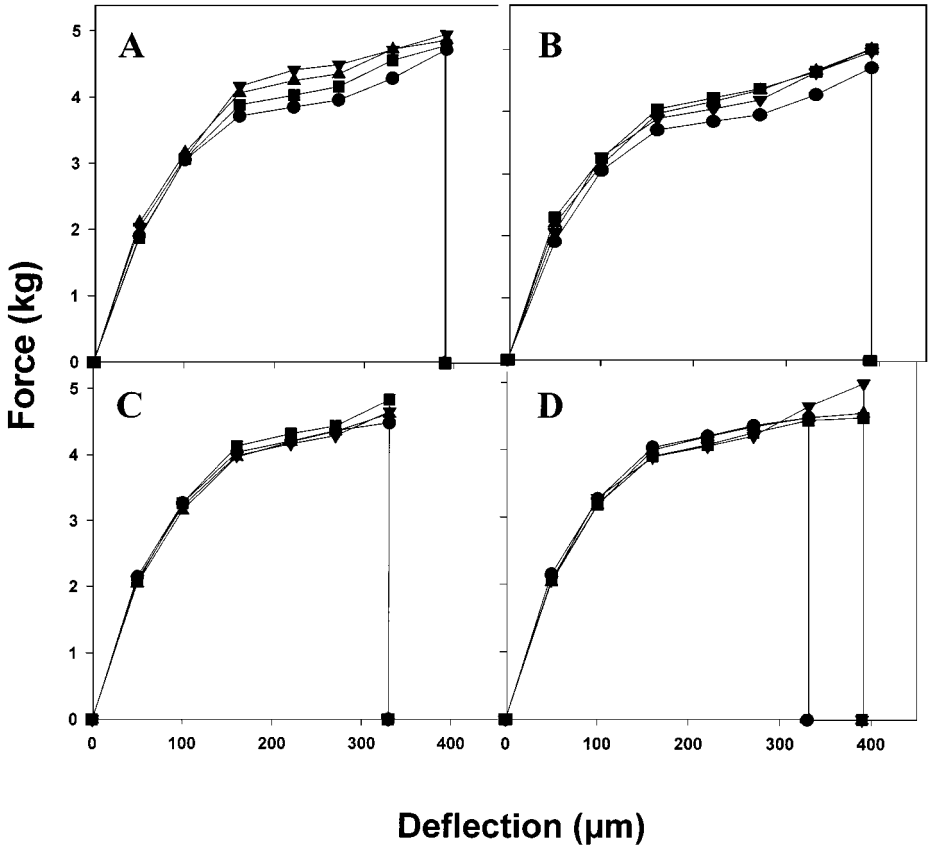

Figure 3. Force-deflection profiles of the acrylic films as a function of surfactant concentration: (A) sorbitan monooleate/TEC; (B) polysorbate 80/TEC; (C) sorbitan monooleate/TBC; (D) polysorbate 80/TBC.

factants emulsifying greater amounts of plasticizer, thus producing films with lower glass transition temperatures.

Internal stress within a polymeric film is one of the two major forces that affect film-tablet adhesion (15). The total stress within a film includes stress due to shrinkage of the film on solvent evaporation, thermal stress due to the differences in the thermal expansion of the film and the substrate, and volumetric stress as the substrate swells on storage and is directly proportional to the elasticity of the film (24–26). Factors that influence the elastic modulus of the polymer, therefore, will affect the internal stresses within the film and ultimately influence polymer adhesion. In an earlier study, increasing the amount of plasticizer in an acrylic polymeric dispersion decreased the T_g and significantly increased the adhesive toughness of the film (15). These findings were attributed to a decrease in the internal stresses within the film, brought about by greater disruption of the intermolecular attractions between polymer chains. In the current study, increased concentration of the surfactants in TBC-containing coating formulations lowered the T_g of the films, indicative of a more plasticized polymer, while the elongation at adhesive failure and the adhesive toughness of the film increased only in the films containing polysorbate 80. Based on the thermoanalytical data, improved polymer adhesion was expected for all the TBC-containing formulations. These findings, therefore, contradict our current knowledge of the relationship between polymer adhesion and internal stress.

In conclusion, our understanding of the mechanisms involved in film-tablet adhesion is still quite limited. The glass transition temperature of the polymer, as an indication of the internal stress of the films, was not found to correlate with film-tablet adhesion. No relationship between tablet wettability and film adhesion could be estab-

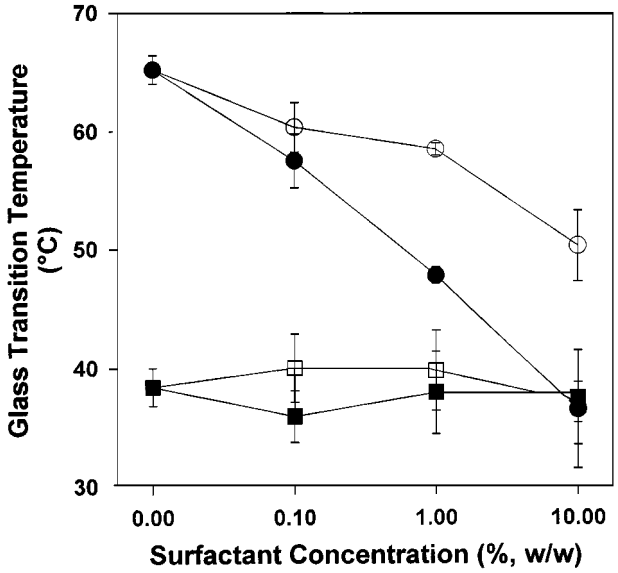

Figure 4. Influence of surfactant concentration on the glass transition temperature of the acrylic film ($n = 3$). ○, sorbitan monooleate/TBC; □, sorbitan monooleate/TEC; ●, polysorbate 80/TBC; ■, polysorbate 80/TEC.

lished for the aqueous-based polymeric dispersions investigated in this study. The findings from the current study demonstrate that the partitioning of hydrophobic plasticizers into the polymer phase of aqueous-based dispersions may be facilitated with the addition of surfactants to the film-coating formulation.

ACKNOWLEDGMENT

This work was supported (in part) by a Pharmaceutical Research and Manufacturers of America Foundation Research Starter Grant.

REFERENCES

1. R. C. Rowe, J. Pharm. Pharmacol., 29, 723–726 (1977).
2. L. A. Felton and J. W. McGinity, Pharm. Dev. Technol., 1, 381–389 (1996).
3. P. Stanley, R. C. Rowe, and J. M. Newton, J. Pharm. Pharmacol., 33, 557–560 (1981).
4. A. O. Okhamafe and P. York, J. Pharm. Pharmacol., 37, 849–853 (1985).
5. R. M. Fung and E. L. Parrott, J. Pharm. Sci., 69, 439–441 (1980).
6. P. D. Nadkarni, D. O. Kildsig, P. A. Kramer, and G. S. Banker, J. Pharm. Sci., 64, 1554–1557 (1975).
7. B. A. Johnson and G. Zografi, J. Pharm. Sci., 75, 529–533 (1986).
8. D. G. Fisher and R. C. Rowe, J. Pharm. Pharmacol., 28, 886–889 (1976).
9. J. A. Wood and S. W. Harder, Can. J. Pharm. Sci., 5, 18–23 (1970).
10. S. Obara and J. W. McGinity, Pharm. Res., 11, 1562–1567 (1994).
11. L. A. Felton, M. M. Haase, N. H. Shah, G. Zhang, M. H. Infeld, A. W. Malick, and J. W. McGinity, Int. J. Pharm., 113, 17–24 (1995).
12. J. C. Gutierrez-Rocca and J. W. McGinity, Int. J. Pharm., 103, 293–301 (1994).
13. F. W. Goodhart, M. R. Harris, K. S. Murthy, and R. U. Nesbitt, Pharm. Technol., 8, 64–71 (1984).
14. B. H. Lippold, B. K. Sutter, and B. C. Lippold, Int. J. Pharm., 54, 15–25 (1989).
15. L. A. Felton and J. W. McGinity, Int. J. Pharm., 154, 167–178 (1997).
16. C.-C. Wang, G. Zhang, N. H. Shah, M. H. Infeld, A. W. Malick, and J. W. McGinity, Int. J. Pharm., 152, 153–163 (1997).
17. G. S. Banker, J. Pharm. Sci., 55, 81–89 (1966).
18. K. Lehmann and D. Dreher, Pharm. Ind., 34, 894–899 (1972).
19. T. Lindholm, B.-A. Lindholm, M. Niskanen, and J. Koskiniemi, J. Pharm. Pharmacol., 38, 686–688 (1986).
20. K. Knop and K. Matthee, STP Pharma Sci., 7, 507–512 (1997).
21. T. Lindholm, M. Juslin, B.-A. Lindholm, M. Poikala, S. Tiilikainen, and H. Varis, Pharm. Ind., 49, 740–746 (1987).
22. J. Siepmann, O. Paeratakul, and R. Bodmeier, Int. J. Pharm., 165, 191–200 (1998).
23. R. Bodmeier and O. Paeratakul, Int. J. Pharm., 103, 47–54 (1994).
24. K. Sato, Prog. Org. Coating, 8, 143–160 (1980).
25. E. Okutgen, J. E. Hogan, and M. E. Aulton, Drug Dev. Ind. Pharm., 17, 1177–1189 (1991).
26. S. G. Croll, J. Appl. Polym. Sci., 23, 847–858 (1979).