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Microwave Heating Effect on Mechanical Properties of Food Packaging Films

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Abstract

The effects of model food, film thickness and microwave heating time on the mechanical properties of food packaging films were examined. Model foods (water, salt solution and vegetable oil) in 2 different plastic pouches of 2 and 3 types of film thickness (3.5, 5.0 mil for FS 5000 series film and 3.5, 4.5 and 5.5 mil for FS 7000 series film, respectively) were microwaved for different durations of time (0, 30, 60, 120, 180, 240 s). Each of 5 samples, 2.54 cm wide and 10 cm long, was cut from pouch samples and conditioned for 48 hr at 50% relative humidity and room temperature in a desiccator before measuring mechanical properties by a texture analyzer. The tensile strength (TS), elongation at break (E) and the Youngs modulus (Y) were significantly affected by kind of model food, film thickness and microwave heating time ($p<0.05$). The TS and E of both films increased as film thickness increased except for FS 7055 film, whereas the Y decreased as the film thickness increased. The TS significantly decreased after 1 min of microwave heating and relatively unaffected after that. The E of FS 5000 series films was significantly affected by the microwave heating time while that of FS 7000 series films was not ($p<0.05$). As the microwave heating time increased, the Y significantly increased rather linearly for both films ($p<0.05$).

Key words: tensile strength, elongation, Young's modulus, microwave, food packaging films

Introduction

The use of microwave energy for heating in food processing has been a great interest to many researchers. Microwave processing can offer several distinct advantages as compared to conventional heating methods. These include rapid heating, energy savings, precise process control and faster start-up and shut-down times (Decareau, 1985). It also offers uniform product heating at reduced surface temperatures (Mudgett, 1982; Schiffmann, 1992) and saves time and space (Kalafat and Kroger, 1973). Applications that are currently being used for several food processing operations include baking, cooking, drying, tempering, pasteurization and sterilization (Giese, 1992). In addition, microwave oven is now one of the common household appliances and are used in many foodservice establishments and households to cook or re-heat food (Huang *et al.*, 1993).

Now-a-days many convenient foods have proliferated into the marketplace. Most of these foods are heated or cooked with their packages in microwave ovens that are considered the most rapid way of reheating food items and energy-efficient. Foods are heated as a result of molecular excitation and foods containing high moisture and fat readily absorb microwaves. During microwave heating, packaging materials are weakened or deformed due to heat energy and the industry uses excess packaging material to avoid these. To minimize excess packaging, it is important to systematically study the effect of microwave on various types of packaging materials and conditions. The mechanical properties of the packaging materials are important data for the assessment of the applicability of those films in microwave heating.

Several researchers have studied mechanical properties of various films (Choi *et al.*, 1998; Cho *et al.*, 1998; Gennadios *et al.*, 1998; Fishman and Coffin, 1998;

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Rindlav-Westling *et al.*, 1998; Handa *et al.*, 1999; Perez-Gago *et al.*, 1999; Guiot *et al.*, 1999; Cunningham *et al.*, 2000); however, the effect of microwave heating on the mechanical properties of food packaging films has not been reported. It is evident from the literature review that information on the mechanical properties as affected by microwave heating is not available. Therefore, this study was undertaken to study the effects of microwave heating on the mechanical properties of food packaging films depending on film type, thickness, microwaving time and model foods.

Materials and Methods

Materials

Two kinds of plastic films (series 5000 and 7000) were obtained from Cryovac Packaging Co. (Duncan, SC, USA). Series 5000 films are medium barrier and contain no EVOH, while series 7000 films are high barrier materials and contain EVOH. The basic structures of these films are LLDPE/tie/Nylon/tie/Nylon/tie/LLDPE and LLDPE/tie/Nylon/EVOH/Nylon/tie/LLDPE, respectively, for series 5000 and 7000 films. Two or three types of film thickness (3.5, 5.0 mil for series 5000 film and 3.5, 4.5 and 5.5 mil for series 7000 film, respectively) were used in this study.

Microwave heating

Each film was cut and made to pouches (16 cm×16 cm) using a heat-sealing machine (Seal Master 230, Audion Electro). Five hundreds mL of each model foods (water, 3% aqueous NaCl, vegetable oil) were placed in the pouches and heat-sealed prior to microwave heating at high setting for different durations of time (0, 30, 60, 120, 180 and 240 s). Temperatures of the model food system were measured right after microwave heating using a digital thermometer (Omega HH82, No. 72JY0423).

Measurements of mechanical properties

Five specimens, 10 cm×2.54 cm, were cut from pouch samples after cleaning with distilled water and conditioned at 25°C and 50% relative humidity for 48 h in a desiccator before measuring mechanical properties by a Sintech texture analyzer (Sintech/10, Sintech Div. of MTS Systems, Corp., USA). Film tensile strength (TS), elongation at break (E) and Young's modulus (Y) were measured according to the ASTM standard method D 882-90 (1991) with a slight modification. TS was calculated by dividing peak load by initial specimen cross-sectional area, and E was expressed as percentage of change of the original length of a specimen between grips (10 cm). Initial grip separation was set at 50 mm and crosshead speed at 100 mm/min. Tests were carried out at 25°C on 5 conditioned samples of each film.

Statistical analysis

Statistical analyses were performed using the Statistical Analysis System (SAS, 1992). Analysis of variance (ANOVA) and means for TS, E and Y values were calculated and Duncan's multiple range test was used to determine significant differences ($p<0.05$).

Results and Discussion

General properties of films

General properties of films used in this study were summarized in Table 1. All films had clear appearance and thickness ranged from 3.5 to 5.0 mils (0.0875 mm to 0.1250 mm; 1 mil=0.025 mm) and 3.5 to 5.5 mils

Table 1. General properties of films*

Properties	FS 5000 series films		FS 7000 series films		
	FS5035	FS5050	FS7035	FS7045	FS7055
Appearance	Clear	Clear	Clear	Clear	Clear
Thickness, mils	3.5	5.0	3.5	4.5	5.5
TS at 22.8°C, MPa	41.4~48.3	44.8~51.7	42.7~51.7	43.4~53.8	44.8~55.2
E at break at 22.8°C, %	500~550	500~600	425~500	440~500	450~550
Heat sealing range, °C	140~190	150~190	150~210	150~210	150~210

* Data supplied by the manufacturer.

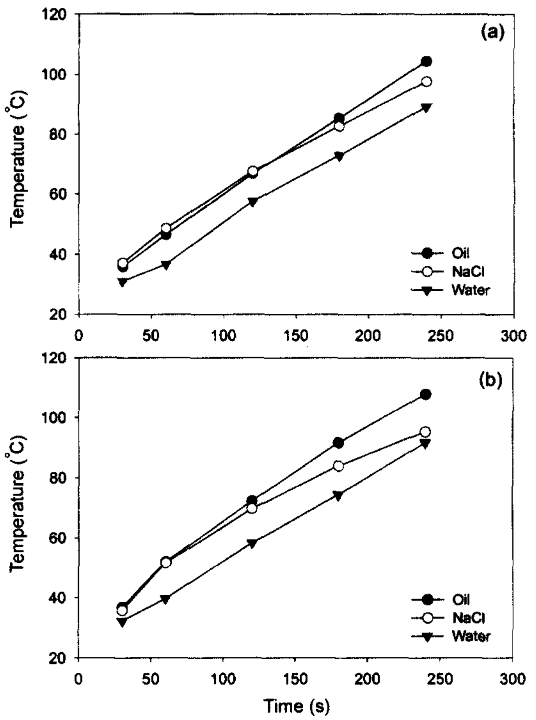

Fig. 1. Typical temperature profiles of model food systems during microwave heating. (a) FS 5035 film and (b) FS 7045 film.

(0.0875 mm to 0.1375 mm) for FS 5000 and FS 7000 series films, respectively. Tensile strength of FS 5000 series films at 22.8°C ranged from 41.4 MPa to 51.7 MPa while that of FS 7000 series films ranged from 42.7 MPa to 55.2 MPa. Elongation percentage at break slightly varied depending on the type of the film and ranged from 500% to 600% for FS 5000 series films, from 425% to 550% for FS 7000 series films, respectively. Both films had a similar heat sealing temperature range of 140-210°C.

Temperature profile during microwave heating

Figure 1 presents typical temperature profiles of model food systems during microwave heating. Similar patterns of temperature rise regardless of film type are shown. The temperatures of oil and salt solution were very close each other. As to water, the temperature started with relatively lower temperature and the end temperature was lower after microwave heating. This is probably due to the differences in the dielectric properties of each model food.

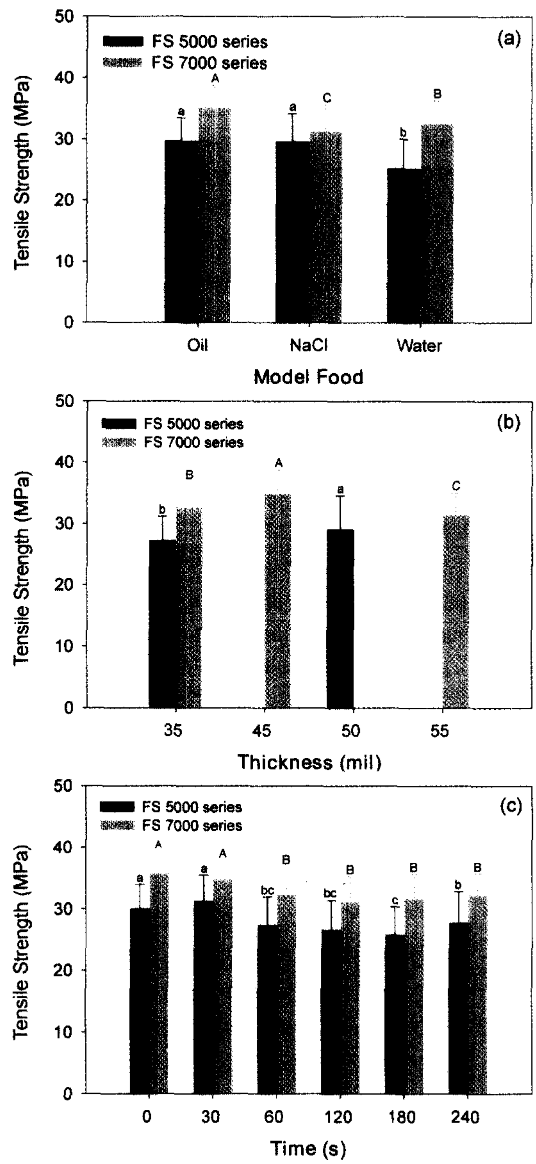

Fig. 2. Effect on the tensile strength of food packaging films as influenced by (a) model food, (b) thickness and (c) microwave heating time. Means within film type with the same letter are not significantly different ($p<0.05$).

Mechanical properties

The tensile strengths of each film as affected by model food, film thickness and microwave heating time were compared (Fig. 2). The tensile strength is the most common means to express the strength and ductility of plastics (Brady and Clauser, 1991). TS is the value of maximum load during a tension test carried to rupture divided by the original cross-section area of the specimen (Park *et al.*, 1993). The TS of each film was significantly influenced by model food system ($p<0.05$). When oil was used as a model food system, the TS was significantly higher regardless of film type. Interestingly, the TS of FS 5000 series films was significantly higher for salt solution; however, the value was significantly lower when FS 7000 series films used.

The TS was significantly affected by film thickness ($p<0.05$). As thickness increased, the TS was significantly increased in general. Although TS should not be influenced by thickness theoretically, it is not uncommon. Park *et al.* (1993) also reported that TS of hydroxypropyl cellulose films increased as thickness increased. It was interesting to note that the TS of FS 7000 series films with 55 mil thickness in our study was significantly lower than that of others with lower thickness ($p<0.05$). Microwave heating time also significantly affected the TS regardless of film type ($p<0.05$). The TS significantly decreased after 1 min of microwave heating and relatively unaffected after that. Increase in the exposure time resulted in relatively weaker films. The effect of microwave heating on tensile strengths was more pronounced in FS 5000 series films than FS 7000 series films; the decrease in TS of FS 7000 series films was less. Arvanitoyannis *et al.* (1998) reported that chitosan and gelatin-based edible films obtained by evaporation at high temperature (c. 60) were weaker, and had lower tensile strength and elongation than those prepared by the low-temperature process. The optimal treatment time for maintaining TS could not be determined. Results suggest that packaging materials are weakened during microwave heating and it depends on the file type, thickness and model food used.

The effects of model food, film thickness and microwave heating time on the E were shown in Fig. 3. Elongation at break, a measure of film strechability before breaking, is an important mechanical property of a packaging material (Banerjee *et al.*, 1996). The E was also significantly affected by type of model system used ($p<0.05$). For FS 5000 series films, the E was significantly lower for water as model food systems while for FS 7000 series film the E was significantly lower for salt solution. The E increased significantly as the film thickness increased for both type of films ($p<0.05$). Similar findings were reported with methyl cellulose films by Park *et al.* (1993).

The microwave heating time also affected the E differently in types of film. The E of FS 5000 series films was significantly affected by the microwave heating time,

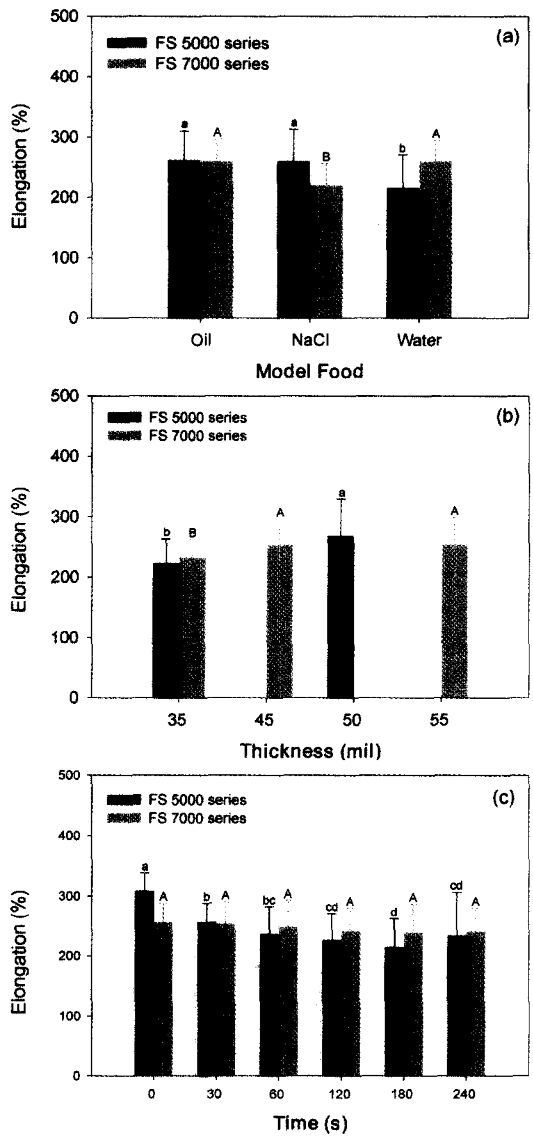

Fig. 3. Effect on the elongation at break of food packaging films as influenced by (a) model food, (b) thickness and (c) microwave heating time. Means within film type with the same letter are not significantly different ($p<0.05$).

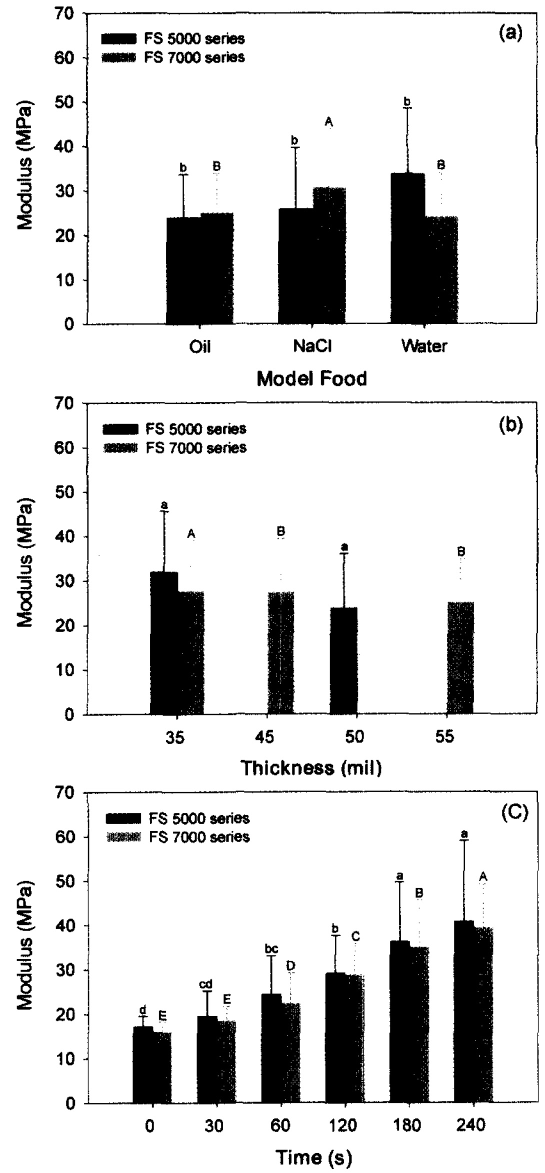

Fig. 4. Effect on the elastic modulus of food packaging films as influenced by (a) model food, (b) thickness and (c) microwave heating time. Means within film type with the same letter are not significantly different ($p<0.05$).

while that of FS 7000 series films was not ($p<0.05$). For FS 5000 series films, the E decreased as the microwave heating time increased, except for 240 s (increased E of 9% compared to 180 s treatment), and films became less stretchable. Similar trend was found in FS 7000 series films but the differences were not statistically significant ($p>0.05$). Banerjee *et al.* (1996) reported that ultrasound treatments reduced elongation at break of milk protein-based edible films, except the sodium caseinate films treated at the highest power intensity. It was noted that the E for both films was relatively lower than that of manufacturer's specification as well as that of synthetic films such as LDPE and Saran which has 300 to 500% E (Briston, 1988; Chen, 1995).

Figure 4 presents the effect on the elastic modulus of food packaging films as influenced by model food, thickness and microwave heating time. All three factors significantly affected the Young's modulus, Y ($p<0.05$). Significantly higher Y was found when water and salt solution were used as model food system for FS 5000 series and FS 7000 series films, respectively. Film thickness also significantly affected the Y. As the thickness increased, the Y decreased significantly for both films. There was a direct relationship between the average Y and microwave heating time. As the microwave heating time increased, the average Y significantly increased rather linearly for both films ($p<0.05$). The results provide valuable information to minimize excess packaging when applied to microwave heating and can be used to recommend for suitable packages based on their intended applications.

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References

Arvanitoyannis, I.S., A. Nakayama and S. Aiba. 1998. Chitosan and gelatin based edible films: state diagrams, mechanical and permeation properties. *Carbohydr. Polym.* **37**: 371-382

ASTM. 1991. Standard test methods for tensile properties of thin plastic sheeting. American society for testing and materials. ASTM designation D 882-90, Philadelphia, USA

Baneerjee, R., H. Chen and J. Wu. 1996. Milk protein-based edible film mechanical strength changes due to ultrasound process. *J. Food Sci.* **61**(4): 824-828

Briston, J.H. 1988. *Plastic films*. 3rd ed., Longman Scientific & Technical, Essex, England

Brady, G.S. and H.R. Clauser. 1991. *Materials handbook*. 13th ed., McGraw-Hill, Inc., New York, NY, USA

Chen, H. 1995. Functional properties and applications of edible films made of milk proteins. *J. Dairy Sci.* **78**: 2563-2583

Cho, S.Y., J.W. Park and C. Rhee. 1998. Edible films from protein concentrates of rice wine meal. *Korean J. Food Sci. Technol.* **30**(5): 1097-1106

Choi, S.J., S.Y. Kim, D.K. Oh and B. S. Noh. 1998. Physical properties of locust bean gum-based edible film. *Korean J. Food Sci. Technol.* **30**(2): 363-371

Cunningham, P., A.A. Ogale, P.L. Dawson and J.C. Action. 2000. Tensile properties of soy protein isolate films produced by a thermal compaction technique. *J. Food Sci.* **65**(4): 668-671

Decareau, R.V. 1985. *Microwaves in the food processing industry.* Academic Press, Inc., New York, USA

Fishman, M.L. and D.R. Coffin. 1998. Mechanical, microstructural and solubility properties of pectin/poly (vinyl alcohol) blends. *Carbohydr. Polym.* **35**: 195-203

Gennadios, A., J.W. Rhim, A. Handa, C.L. Weller and M.A. Hanna. 1998. Ultraviolet radiation affects physical and molecular properties of soy protein films. *J. Food Sci.* **63**(2): 225-228

Giese, J. 1992. Advances in microwave food processing. *Food Technol.* **46**(9): 118-123

Guiot, O., L. Tighzert and X. Coqueret. 1999. Electron beam crosslinking of extrusion-blown LDPE films: 1. Mechanical properties. *Euro. Polym. J.* **35**: 565-570

Handa, A., A. Gennadios, G.W. Froning, N. Kuroda and M.A. Hanna. 1999. Tensile, solubility, and electrophoretic properties of egg white films as affected by surface sulfhydryl groups. *J. Food Sci.* **64**(1): 82-85

Huang, Y., C. Leung, M.A. Harrison and K.W. Gates. 1993. Fate of *Listeria monocytogenes* and *Aeromonas hydrophila* on catfish fillets cooked in a microwave oven. *J. Food Sci.* **58**(3): 519-521

Kalafat, S.R. and M. Kroger. 1973. Microwave heating of foods-Use and safety considerations. *Crit. Rev. Food Technol.* **4**(2) 141-145

Mudgett, R.E. 1982. Electrical properties of foods in microwave processing. *Food Technol.* **36**(2): 109-115

Park, H.J., C.L. Weller, P.J. Vergano and R.F. Testin. 1993. Permeability and mechanical properties of cellulose-based edible films. *J. Food Sci.* **58**(6): 1361-1370

Perez-Gago, M.B., P. Nadaud and J.M. Krochta. 1999. Water vapor permeability, solubility, and tensile properties of heat-denatured versus native whey protein films. *J. Food Sci.* **64**(6): 1034-1037

Rindlav-Westling, A., M. Stading, A. Hermansson and P. Gatenholm. 1998. Structure, mechanical and barrier properties of amylose and amylopectin films. *Carbohydr. Polym.* **36**: 217-224

SAS. 1992. *User's Guide: Statistics*, SAS Institute, Inc., Cary, NC, USA

Schiffmann, R.F. 1992. Microwave processing in the U.S. food industry. *Food Technol.* **46**(12): 50-56