Society of Plastics Engineers
PLASTICS RESEARCH ONLINE

10.2417/spepro.005919

Improved puncture resistance testing of flexible food packages

Leopoldo Carbajal, Rong Jiao, Diane Hahm, Barry Morris, and Randy Kendzierski

A high-speed impact test for measuring puncture resistance of multilayer films was developed that shows good correlation with field failures and helps optimize performance for food packaging.

Flexible packaging is one of the fastest-growing segments in the packaging market, since it provides protection with less material and cost than the rigid packaging forms it often replaces. Multilayer structures—films made from a combination of materials—are used to provide the desired features at the lowest cost. Optimizing the design of such structures is one of the key challenges facing the packaging engineer. For this, it is useful to run laboratory tests that mimic packaging failures in controlled conditions. Measurements from such tests can then be used to construct models that predict the performance of multilayer films based on the constituent layers. However, there is often a lack of good laboratory tests that correlate with outcomes of field trials and also provide adequate data for modeling.

One such area, for which better tests are needed, is puncture resistance. Many food products, such as crackers and dried pasta, have sharp edges that can puncture flexible packaging during filling and handling. Standard film tests such as the ASTM falling dart test and the Elmendorf tear test do not correlate well with package failures recorded in the field,[1–3] forcing engineers to conduct expensive prototype testing on actual packing lines to evaluate design changes. Scratch tests have been developed that better match the outcomes of field trials,[3] but they do not yield quantitative data suited for developing predictive models, which is our ultimate goal.

To fill this gap, we sought to devise a new laboratory test that better reproduces the puncture event (as it occurs during the fill operation in a packaging line), and provides data suitable for modeling. We recognized that puncture of flexible packaging has several unique characteristics, including the speed of the event, the diameter of the punctured holes, and the relative low stiffness and strength of the food. Our approach[4] was to first study impact events of food dropping onto films with high-speed photography. From this we designed a high-speed impact test that mimics the puncture event.

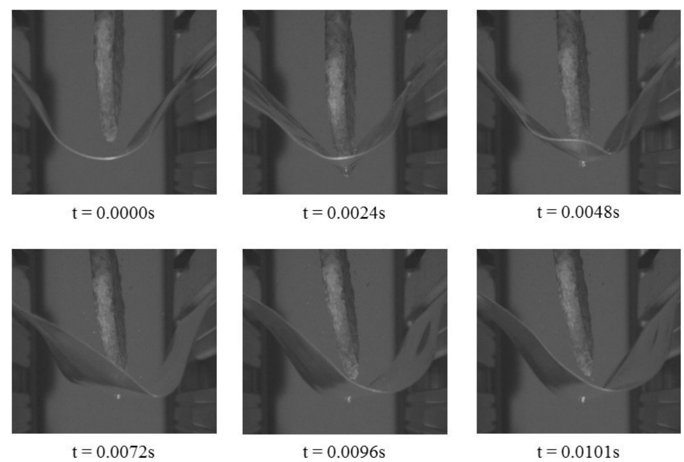

***Figure 1.** A time sequence of a woven wheat cracker dropping on film, captured using a high-speed video camera.*

Finally, we validated the test by measuring the performance of multilayer films, and checking it against a projectile drop test that typically correlates well with field trials.

We selected woven wheat snack crackers for the food drop tests. Figure 1 shows a drop sequence captured by the high-speed video camera. This work allowed us to establish the velocity at which the cracker punctures the film (6.3m/s for the event in Figure 1), the typical size of the puncture holes, and the fact that the cracker does not deform significantly during the event. Based on these observations, we developed a reverse impact puncture test assembly, shown in Figure 2. A steel needle probe mimics the cracker, and a high-speed platform is used to drive the mounted film into the instrumented probe. Our instrumented probe provides a profile of the force versus displacement, from which the ultimate work is calculated (as the area underneath the force-displacement curve). We use the ultimate work from this test as our measure of puncture resistance.

A series of five-layer films were made to validate the test method. The layers consisted of high-density polyethylene (HDPE), tie resins (tie), polyamide (PA), and a blend of ethylene vinyl acetate and

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ionomer as the sealant. The basic structure was (HDPE-tie-PA-tie-sealant), which is one often used in dry food packaging. We varied a number of compositional parameters, but will focus on the %PA in this

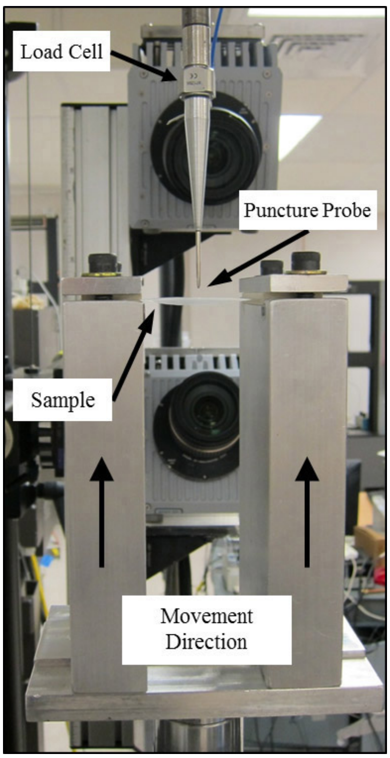

Figure 2. *A new reverse impact puncture test was developed to better mimic puncture events occurring during the packaging fill operation.*

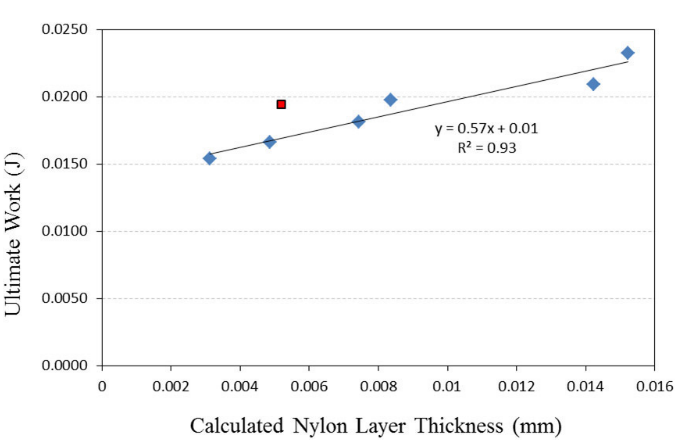

Figure 3. *Increasing the thickness of the PA (nylon) layer increases the puncture resistance (ultimate work), as determined by the new test rig.* R^2*: Coefficient of determination.*

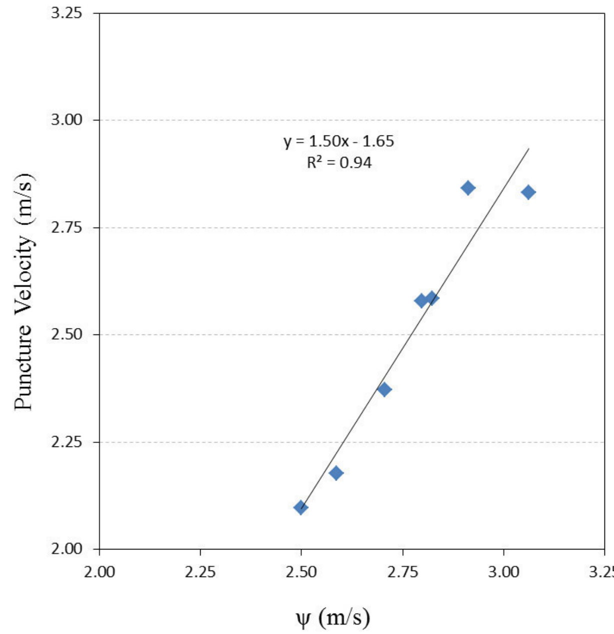

Figure 4. *Correlation of puncture velocity from the projectile drop test with ultimate work from the new impact puncture test (using a transformational parameter* ψ*).*

report. Since PA is a very tough material, we expected that increasing the amount of PA in the film would increase the puncture resistance as determined by our test. This turned out to be true, as is shown in Figure 3. There is one outlier, highlighted in red, that will be the focus of future work.

To establish how well our new puncture test mimics the real-world fill operation, we compared it against a ‘projectile drop test,’ which is known to correlate well with actual packing line trials. (Note that this test differs from the ASTM falling dart test, which does not correlate with field trials). The projectile drop test involves dropping a number of projectiles from a given height onto the film, and then counting the number of punctures. It only gives a ranking of structures, from those with the fewest to the most punctures, and so does not provide the quantitative information needed for modeling that our test provides. We used high-speed video cameras to measure the velocity for puncture in the projectile drop test, and compared it against the puncture velocity as determined in our impact puncture test: Figure 4 shows that the correlation between the two is excellent.

In summary, by studying the puncture dynamics of single crackers dropping on films, we developed a high-speed impact test that provides quantitative data on packaging structures. Our results show clear correlation between design parameters such as the %PA in the film structure

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and rank performance information consistent with empirical drop tests. Our future plans involve continuing to study the design parameters that influence puncture resistance, such as sealant type, layer location, and interlayer adhesion. We are also developing a computer model that will allow us to predict the puncture performance of packaging films.

Author Information

Leopoldo Carbajal, Rong Jiao, and Randy Kendzierski
DuPont Engineering Research and Technology
Wilmington, DE

Leo Carbajal is an engineering research senior associate. His expertise is in computational and experimental mechanics with a strong focus on impact mechanics and failure mechanics of polymers and composites. He works on research and application development programs for all DuPont businesses.

Rong Jiao is a finite element analyst. He focuses on understanding and modeling the response of polymers and composites in end use application development and research programs for all DuPont businesses.

Randy Kendzierski is an engineering mechanics technologist. He focuses on medium to high strain rate testing of polymers and composites for end use application development and research programs for all DuPont businesses.

Diane Hahm and Barry Morris
DuPont Packaging and Industrial Polymers
Wilmington, DE

Diane Hahm works in technical service and has over 30 years of experience in developing flexible packaging structures using ethylene copolymers. A graduate of Tufts University, she holds a BS in chemical engineering.

Barry Morris is a technical fellow at DuPont. In his R&D and application development role for the company's ethylene copolymer business, he has developed a number of models for optimizing flexible packaging structures. He is an SPE Fellow, a member of the board of the Flexible Packaging Division, and a former chair of the Extrusion Division.

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