Technology developments behind heat-sealable substrates

By Eldridge M. Mount, president, EMMOUNT Technologies

Introduction

Substrates generally are used for packaging and "industrial" applications. While the substrates themselves are essentially the same, there are differences in the principle considerations between packaging and industrial films. A primary difference is that most packaging films are used for food and, therefore, must be FDA-compliant in the US or must meet other food-approval standards in other locations around the world. Food approval is based first on the polymer composition but more particularly on the additives compounded into the substrate, which might wind up in the foods by migration. Industrial films, while not requiring specific approvals for foods, still will share many of the same concerns about the migration of the additives, but mostly how they affect the performance of the substrate or by contamination of the product being packaged in the application.

I have written on film additives in the past, and the reader is encouraged to review these if interested. However, for this article, I want to focus on the various heat-sealing technologies, important polymer characteristics and film designs used to make heat-sealable substrates. Film substrates today are usually based on polypropylene (PP), oriented (OPP) or cast (CPP); oriented polyester (OPET); and Nylon films. For other polymer substrates, the general concepts of product design and sealing requirements will be the same, but the ranges of temperatures will be different based on the thermal properties of the substrate polymer chosen, and this will control the selection of the sealant polymers.

Heat-sealing methods

In general, heat seals are formed by thermally welding two substrate surfaces together between two platens or "jaws" by melting the sealant(s) at a specific temperature under a specific force for a specific time period. For most sealing machines, these are denoted as the "sealing temperature," the sealing "jaw pressure" and the "dwell time," respectively. The two jaws may both be heated or, in some applications, only one jaw is heated. The pressure ensures intimate contact of the substrate surface-weld formation, and the dwell time is necessary to allow sufficient time for the thermal energy of the jaws to conduct to the welding surface and raise the sealant temperature above the melting point to form the weld. Thus, the heat-sealing of substrates will follow the heat-transfer laws for thermal conduction through a solid.

In sealing systems where the sealant surface is heated by hot air or radiation and then welded together under pressure, the engineering principles will be related to the laws of forced convection or radiative heat transfer and surface cooling. For the remainder of this article, I will be focused on sealing between two jaws, but again the principles of polymer selection and product design will be essentially the same with some refinement on sealant polymer properties. With the surface heating from air heating and perhaps radiant heating, it can be possible to form a welded seal from a single polymer substrate. However, the majority of heat-sealable substrates are made by applying a low-temperature sealant to the base substrate by coextrusion, lamination, or solution or extrusion coating. A heat-sealable substrate can be made in many ways – limited only by your imagination, cost and the availability of specific polymer-layering technologies to you.

Initial product design

Figure 1 shows the product design of a one-sided, heat-sealable substrate with a treated surface or surface layer suitable for printing or converting. The most general and controlling concept in multilayer, heat-sealing substrates is that the sealant polymer must be at or near the product surface, and must melt below the melting point or heat-distortion temperature of the substrate base polymer. By heat distortion, I mean the thermally induced change in the substrate, such as shrinkage, embrittlement, etc., which will ruin the substrate and impact the formation of the heat-sealed package, making it unsuitable, either in appearance or in the integrity and durability of the heat-sealed package. In some applications, the strength of the weld must remain high during the cooling of the seal while product is added to the formed package. The ability of a hot seal to maintain the integrity of the seal often is called "hot tack" and is related to the rate of crystallization of the polymers in the sealant. This is polymer-specific, and sealant

Treated surface or surface layer	
Bulk or core layer	75% to 97%
Heat-sealing layer	25% to 3%

FIGURE 1. *One-side heat-sealable substrate, oriented or cast film with treated surface, and a typical range of relative thicknesses of the bulk and sealant thicknesses*

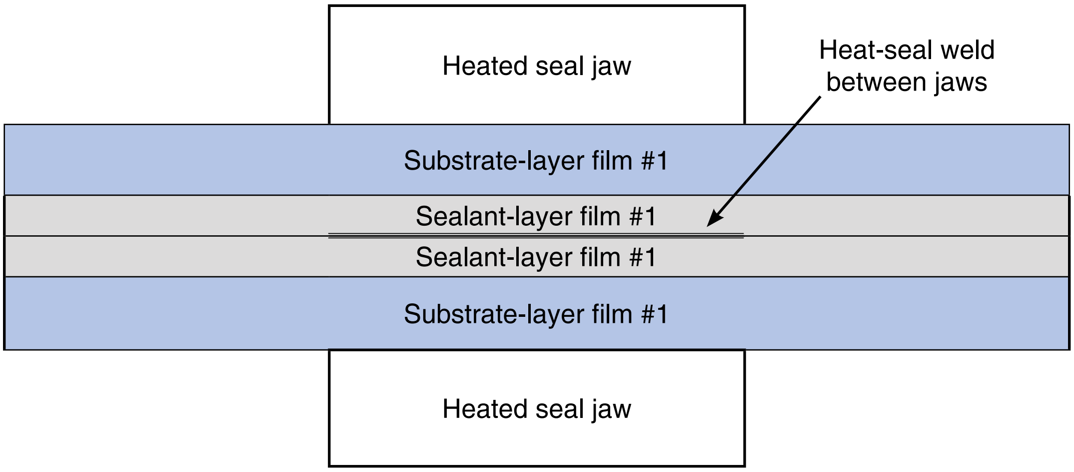

FIGURE 2. *Heat-sealing two identical heat-sealable film surfaces together with heated sealing jaws. Sealable surfaces melt and weld together due to the jaw temperature, pressure and dwell time of the closed jaws. Jaw temperature is below the melting or distortion temperature of the substrate layer and above the melting point of the sealant layer.*

resins must be chosen for their hot-tack performance if this is a requirement of the application.

The bulk of the substrate must melt above the sealant temperature because we are heat-welding an interior surface of the substrate by heating with jaws from the outside surface away from the welding surfaces (see Figure 2). The temperature difference in the melting points of the sealant polymer and the heat-distortion temperature of the substrate polymer will control the temperature range of sealing, i.e.: the temperature range over which the heat-sealing substrate will first form a functional seal to the point where the substrate is ruined by the sealing jaw. The meaning assigned to “seal” also will impact the value of the seal range. For instance, for many applications the weld formed as the seal must exceed some specified value of minimum seal strength, and the jaw temperature at which this seal strength is reached is termed the “seal initiation temperature” or perhaps the “minimum sealing temperature.” A representative heat-seal strength curve for a polyolefin film is shown in Figure 3.

Heat-seal strength testing

The strength of the heat seal generally is determined by peeling the sealed surfaces apart and measuring the force required to separate the two surfaces or to tear the film into two pieces. There are many ASTM and other national or industry-standard test methods for seal strength, with some specific to various applications or industries. Figure 3 shows a graph of a typical heat-sealing curve obtained by measuring the strength of the seal formed at various temperatures. We can see in Figure 3 that the strength increases with increasing jaw temperature as the strength of the weld increases to a maximum. The seal strength often will decrease with increasing temperature above the maximum due to substrate damage during heating or overheating of the sealant polymer. Seal-strength values also are controlled by the dwell time, the jaw pressure and the design of the sealing jaw. These values should be selected to mimic your heat-sealing process and machine for the heat-seal profile to be meaningful in the selection of heat-sealing films for your application.

Figure 4 plots seal-strength profiles for three films prepared with three different polymer sealants at two different sealant thicknesses. It is readily apparent from Figure 4 that sealant thickness affects the strength of the seal and that various polymers have their own specific seal-strength characteristics, based on the polymer properties of the sealant. It is apparent from Figures 3 and 4 that the selection of sealant films can be a matter of sorting through a variety of sealant polymers and product designs with

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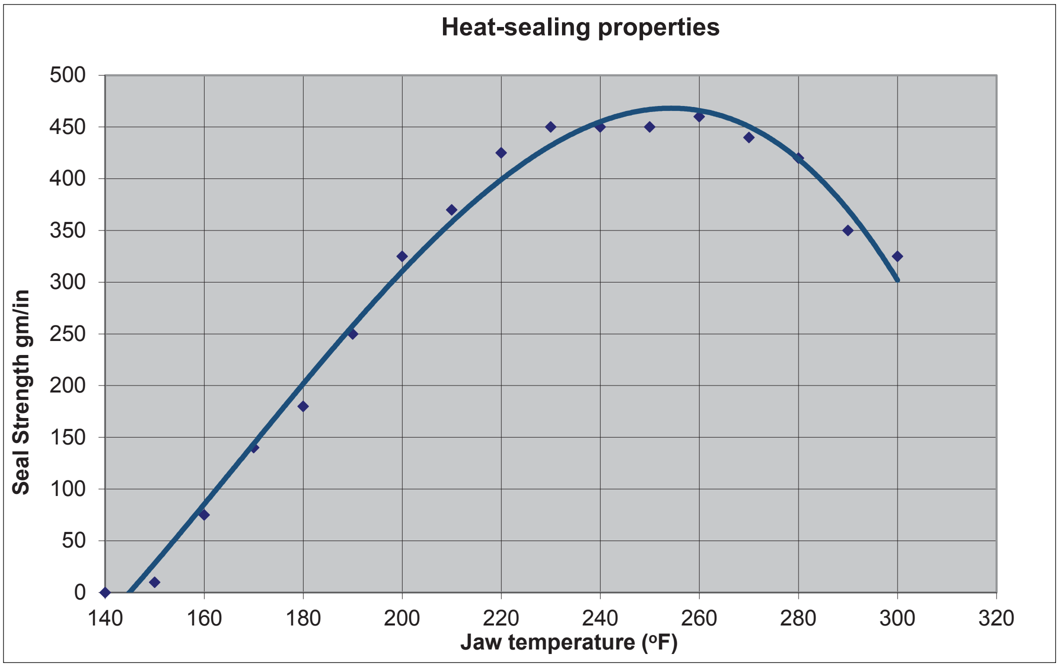

FIGURE 3. *Representative heat-seal range of heat-sealable substrates. Minimum sealing temperature is a defined value of jaw temperature at which the minimum acceptable seal strength is reached. The upper sealing temperature is defined as the point where an unacceptable seal is formed. The seal range is the number of degrees between the minimum and upper sealing temperatures. Seal range is affected mostly by the sealant melting point and to some degree by the sealant thickness, the jaw pressure and dwell time.*

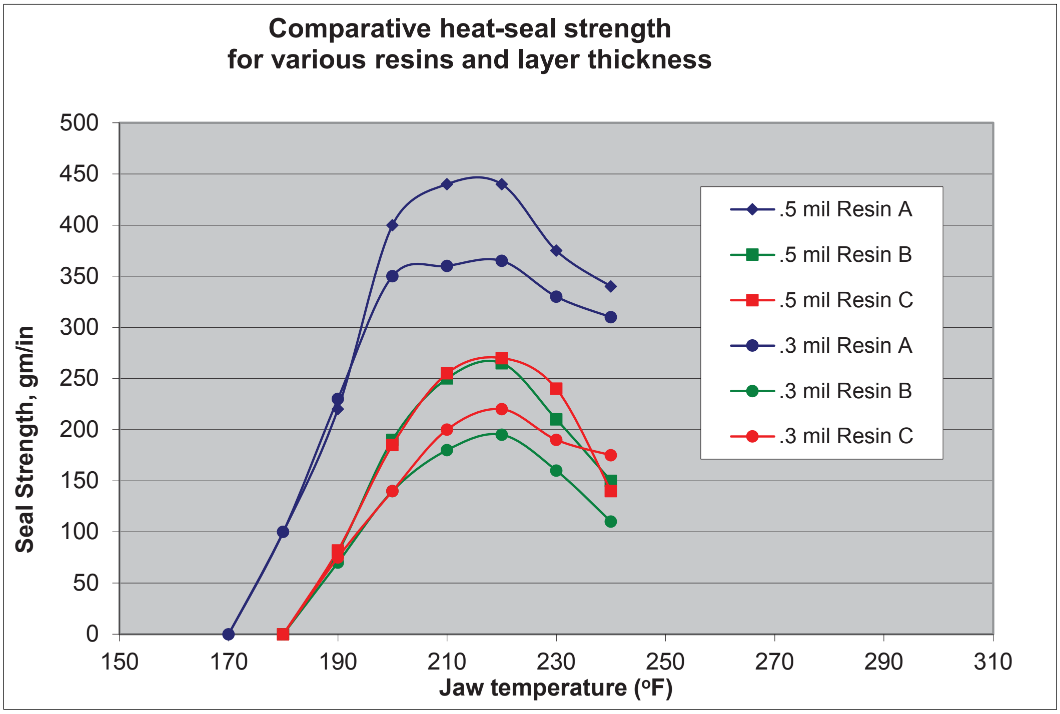

FIGURE 4. *Representative heat-seal range of heat-sealable substrates with three different melting-point sealant polymers at two different sealant thicknesses.*

various sealant thicknesses to design or find the proper heat-sealable substrate for a specific set of requirements.

To this point, I have focused on weld seals from the same sealant polymer and, in general, the weld strengths can be designed to give a destruct seal, i.e.: where the substrate tears before the seal peels, which is oftentimes the desired seal-failure mode. It is not apparent from Figures 3 and 4 at what temperature this might occur or if the seals are, in fact, peeling. So, it is important to have this sort of information recorded during the testing if it's important to the application. Seal jaw type, temperature and alignment can impact the onset of a film tear on seal opening. Substrate failure in seals usually requires an interfacial strength of the sealant to the substrate which exceeds the tear strength of the substrate. This is easily obtained by using sealant and substrate layers of the same polymer family, such as EPcopolymer sealants with PP substrates or PETG with PET substrates.

Forming peelable seals

The formation of peelable seals, i.e., seals that separate while not tearing through the base polymer substrate, are fairly easy to understand. In general, there are several principal ways to form them. Case 1 is to have two incompatible-polymer heat-sealing surfaces welded together; Case 2 is to have a blend of two incompatible polymers blended together as the sealant layer; Case 3 uses a block-copolymer sealant; and Case 4 is to have a one- or two-layer sealant where the welded, sealed surfaces either delaminate

Thin, formulated heat-sealing layer	2% to 3%
Thick, low-melting sealant	20% to 30%
Bulk or core layer	75% to 65%
Treated surface or surface layer	3%

FIGURE 5. *High-strength, hermetic or liquid-tight heat-sealing film design with thin formulated sealant cap to improve heat-sealing machine performance. Biaxially oriented films with thick sealant layers can in some instances approach the seal strength of cast films.*

from the bulk substrate or from a second, inner layer of the sealant.

While this seems straightforward, it can be hard to engineer the exact peel strength in the sealant layer that is desired. A wide range of polyolefin polymers is available for various layers for Case 1, but this then requires the use of two films in inventory. For Case 2, the quality and uniformity of the polymer blend can drive variations in one roll to another, or lot-to-lot peel strength. In this regard, block copolymers are better because the molecular composition is more uniform, but block copolymers are generally more expensive than blends. A two-layer sealant as defined in Case 4 is generally consistent in its peel strength but will require coextrusion or multiple steps to obtain the desired sealant structure.

To obtain hermetic or liquid-tight seals usually requires the use of thick, low-melting polymer sealants to obtain the desired seal integrity. However, these sealing surfaces can be difficult to produce or difficult to use on heat-sealing machines due to the difficulty in formulating the sealant surface for heat-sealing machine performance. Thick, low-melting surfaces tend to jam, tear or stick to hot machine surfaces. Therefore, an approach was developed where the thick, low-melting polymer was capped with a thin, formulated second polymer layer (see Figure 5). The idea is that the thin outer skin of the low-melting sealant polymer is more effectively formulated for sliding on hot machine surfaces, or it can even be a slightly higher-melting polymer than the bulk low-temperature sealant layer. Then during heat-sealing, the thin outer layer is breached and the inner polymer layer forms the weld seal.

The type of the substrate film, oriented or cast, also can impact the measured seal strength. Once a weld is obtained in the sealant layer, oriented films will oftentimes tear at low elongation due to the orientation, and the seal strength is actually the measured force to tear the film through its thickness. In comparison, cast films, once welded with little orientation, will stretch during

"It can be hard to engineer the exact peel strength in the sealant layer that is desired."

the seal test and give high strengths due to the force required to stretch and tear the film to breakage.

This short article is far from comprehensive, but hopefully it helps in understanding the primary ways to achieve or characterize a heat-sealing substrate. ■

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