

Innovations in Bonding to Low Surface Energy Surfaces

Introduction

When seeking to manufacture a plastic-based part, there are more options for attaching parts together than ever before. In the past Low Surface Energy (LSE) plastics, such as Thermoplastic Polyolefin (TPO), Polypropylene (PP), and Polyethylenes (e.g. HDPE) had to be mechanically attached or solvent welded since true adhesive bonding did not work well with these materials. Mechanical attachments (such as clips, screws, etc.) can be used with virtually any surface but they require additional steps to mold or create features for the attachment, can lead to stress concentrations which may result in plastic cracking and premature failures, and often result in unsightly surfaces. Solvent welding has the disadvantage of relying on the use of hazardous and noxious solvents.

In the past decade new adhesives and bonding tapes have been formulated which allow robust bonding of many of these low surface energy plastics. This allows manufacturers to take advantage of the benefits of using adhesives and bonding tapes including design flexibility, stress distribution, bonding dissimilar materials, and using lighter/thinner materials as well as a clean final bond appearance.

Bonding Fundamentals—why LSE Surfaces are Hard to Bond

Adhesive bonding of metals, paints and plastics has been common for many years with a wide variety of adhesive technologies available, including structural adhesives (epoxy, acrylic, urethane), non-structural adhesives (hot melt, contact adhesives) and pressure sensitive adhesives (peel and stick bonding tapes). But until recently these adhesives were not used on tougher-to-bond thermoplastic materials including TPO, polypropylene and polyethylene because of their surface characteristics.

For an adhesive to be useful it must achieve adhesion to the substrate surface. Adhesion depends largely upon surface phenomena – the adhesive must flow out on and appropriately interact with the surface of the parts to be joined. The adhesive must be able to make intimate contact with the surface of the substrate. Such intimate contact is called “wetting out” the surface, and refers to the adhesive’s ability to spread over the surface. While adhesives use different mechanisms to flow and achieve contact – structural adhesives are low viscosity liquids before curing, hot melt adhesives are heated to a flowable viscosity at application, and pressure sensitive adhesives make use of their unique viscoelastic nature to flow – in all cases the ability of the adhesive to wet the surface is important. In addition to the chemical make-up of the surface, the texture, porosity, and any contamination or barriers that coat the surface of the substrate (such as mold release agents, process additives which bloom to the surface, or contaminants from handling) can affect the adhesive’s ability to flow and achieve intimate contact.

Even if cleaned of such barriers and contaminants, some surfaces such as TPO, PP and PE may resist being wetted by an adhesive. This is because of a phenomenon referred to as surface energy. Surface energy is the excess energy that exists at the surface (as opposed to the bulk) of a solid; this excess energy exists because molecules at the surface cannot interact with as many like neighbors as molecules in the bulk are able to do; therefore, they have excess interaction energy.

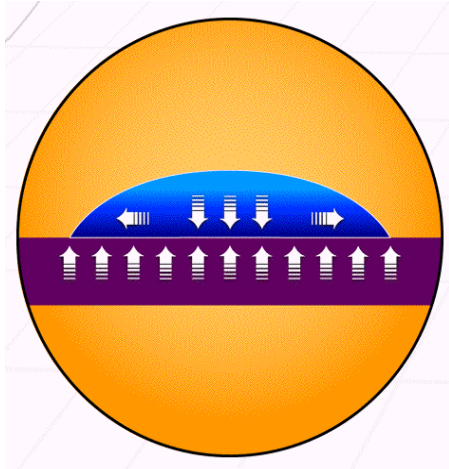
The surface energy of a solid varies with its chemical make-up as shown in the table below. Note that metals and glass have a high surface energy and are easier to bond; whereas plastics have a lower surface energy and are harder to bond. Hardest of all are the low surface energy plastics in the first several rows of the table.

Solid Surface	Critical Surface Tension (mN/m)
Polytetrafluoroethylene (PTFE)	18.5
Silicone	24
Poly(vinylidene fluoride)	25
Polyethylene (PE)	31
Polypropylene (PP)	31
Polystyrene	33
Poly(vinyl chloride) (PVC)	39
Nylon-6,6	43
Poly(ethylene terephthalate) (PET; Polyester)	43
Aluminum	~500
Glass	~1000
Iron Oxide	~1350

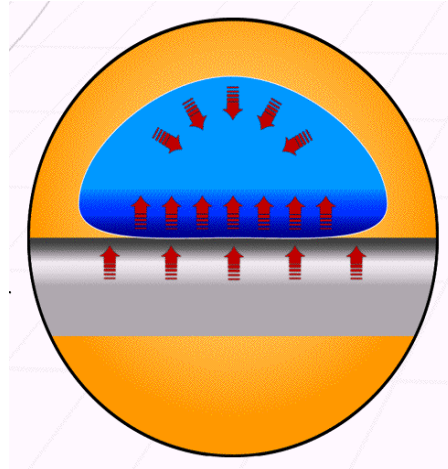
Surface energies of common substances

Table adapted from: *Adhesion and Adhesives: Science and Technology*; Anthony J. Kinloch, New York: Chapman and Hall (1987).

A related concept is the surface energy (or surface tension) of a liquid, which is the amount of excess energy at the surface of the liquid. Surface tension exists because molecules in the bulk liquid are in a lower energy state than at the surface. When a liquid is placed on a solid surface what happens depends on the *relative* surface energy of the liquid compared to the surface energy of the solid. If the liquid has a higher surface energy than the attractive forces between the liquid and the solid surface, the liquid will prefer to maintain its spherical form. Raindrops bead up on a freshly waxed car because the surface energy of the water is higher than that of the wax. When this phenomenon happens between an adhesive and a substrate the adhesive will not spread and make intimate contact with the surface to be bonded; rather, the liquid molecules will tend to remain associated with themselves rather than the surface. The result is lower bond strengths. In contrast if the surface energy of the adhesive is less than that of the substrate the adhesive will spread out and wet the substrate, thus making the intimate contact necessary for good bonding.



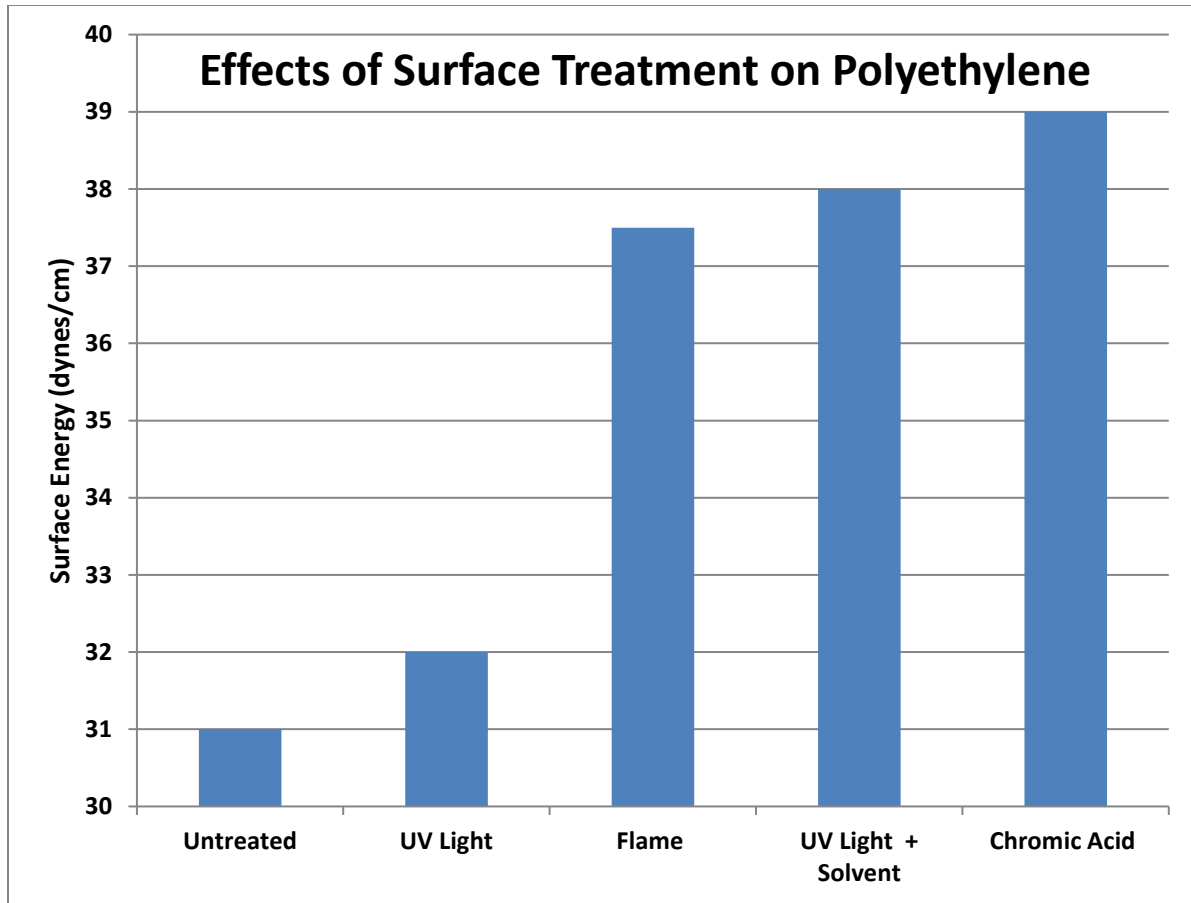
*Solid surface has high surface energy;
Liquid will spread or “wet out” the surface.*



*Solid has low surface energy; adhesive
Will bead up on the surface.*

Therefore, high surface energy (HSE) materials such as metals and glasses can be readily bonded with a variety of adhesives which will be strongly attracted to the solid. Medium surface energy (MSE) materials such as Polyester and PVC can be bonded with many adhesives, but low surface energy (LSE) materials are very difficult to bond. Wet out becomes a challenge unless the surface is modified, since the unmodified surface has such a low surface energy. The surface energy of the liquid adhesive is likely to be higher than the surface energy of the solid.

While some adhesives are available to bond LSE materials, another strategy is to use surface modification techniques which can change the chemical composition of the surface to increase the surface energy and allow a broader number of adhesives to be considered. These techniques include flame, corona or plasma treatment, acid etching or use of solvent-based adhesion promoters that contain higher surface energy resins which entangle with the low surface energy substrate when the solvent swells the surface. Once the surface is modified it is easier for the adhesive to flow out on or wet the treated surface and make a suitable bond. While surface modification might be needed in some cases, typically it will add cost and complexity and may also present environmental or safety issues.



Increase in surface energy of Polyethylene after several common surface treatment methods.

Chart adapted from: **Rauhut, H.W. *Adhesives Age* 13(1), p. 34 (1970).**

New Methods for Bonding LSE Plastics

Technology has advanced to the point where adhesives are available that are capable of high performance bonding to LSE substrates such as TPO, PP and PE without surface treatment. Easy-to-use adhesion promoters are also available as a companion to some adhesive product types to increase the strength and broaden the selection.

Structural Adhesives:

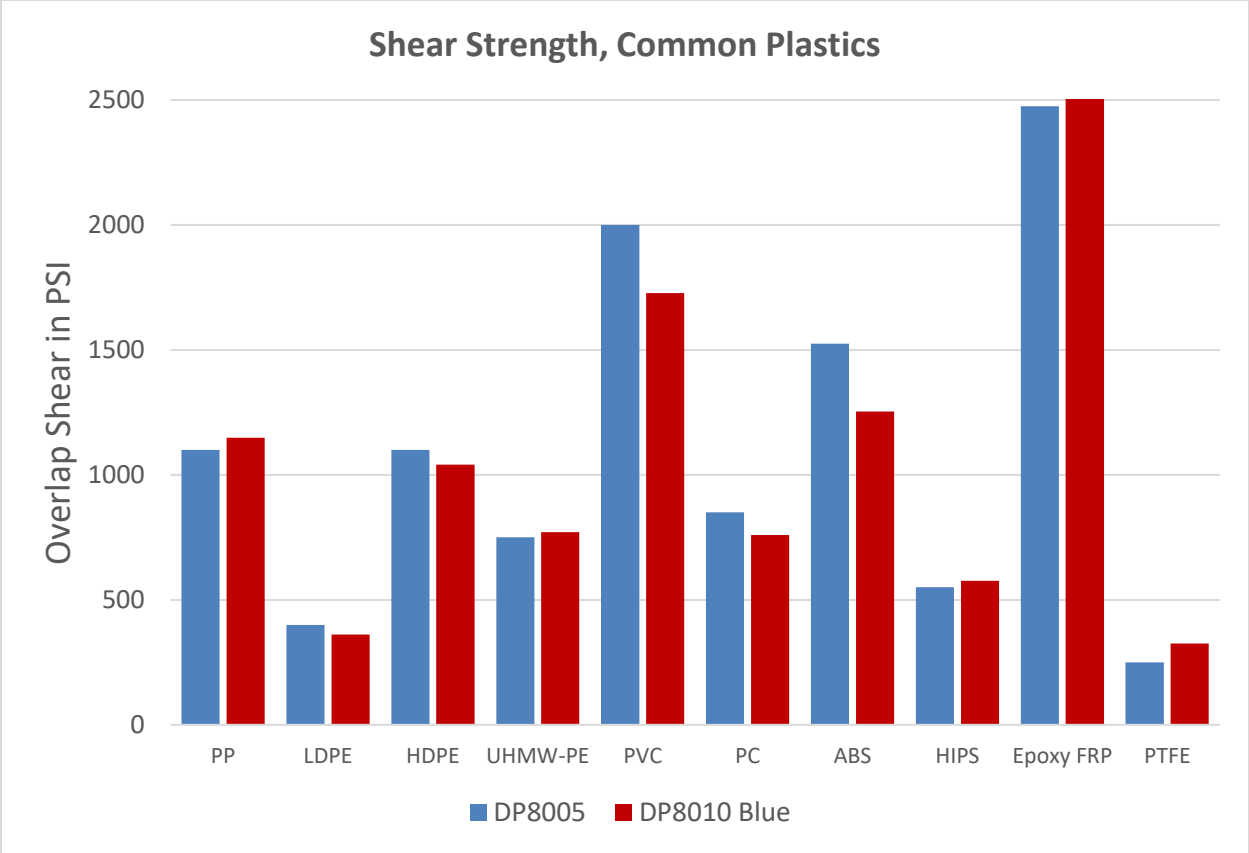
3M™ Scotch-Weld™ Structural Plastic Adhesive DP8005 and 3M™ Scotch-Weld™ Structural Plastic Adhesive DP8010 Blue are uniquely formulated to bond to LSE plastics (as well as high surface energy plastics and metals). These are two-part, solvent-free, room temperature curing adhesives that come in a convenient duo-pak format or, for large applications, in bulk. They resist many chemicals, water, humidity and corrosion. Generally surface preparation is limited to solvent cleaning (to remove surface contaminants). Sometimes, light abrasion or a matte finish on the bonded surfaces can increase bond strengths.



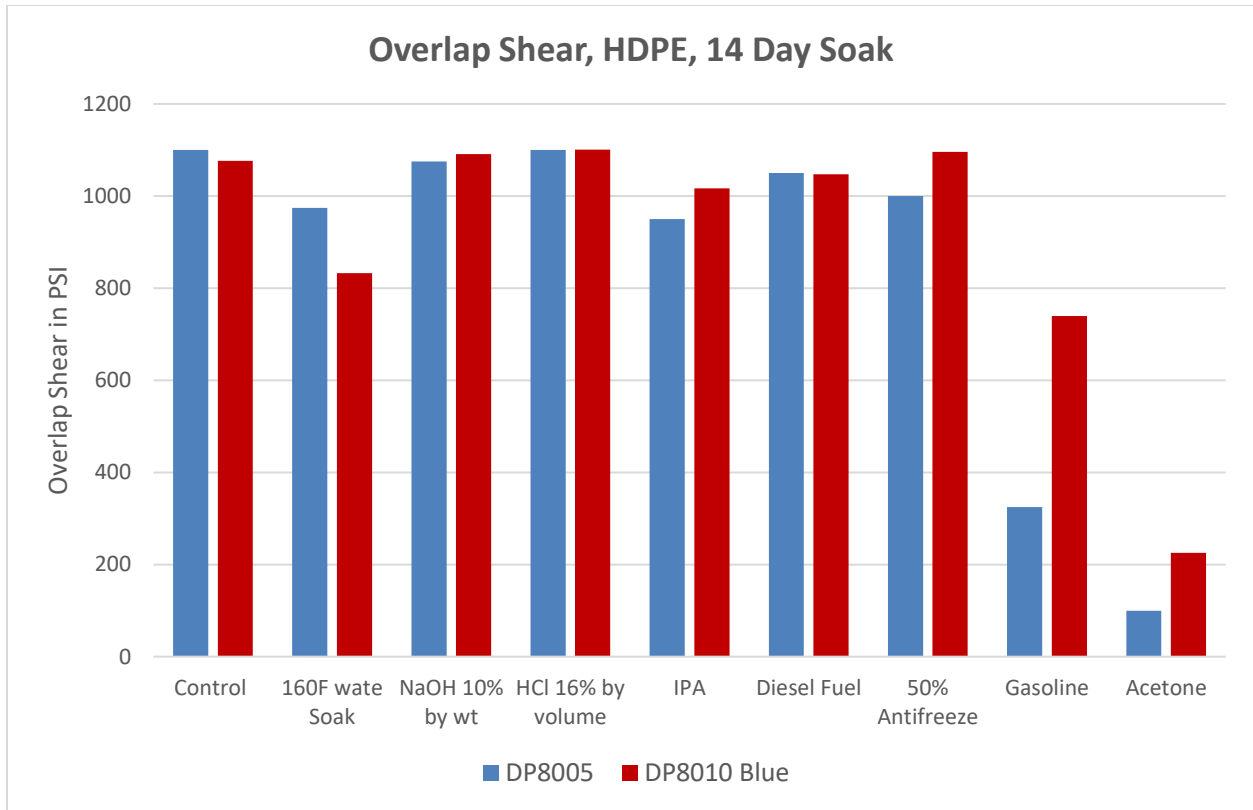
3M™ Scotch-Weld™ Structural Plastic Adhesive DP8005 in a Duo-Pak cartridge with disposable static mix nozzle being applied to a plastic part.

Adhesion strength of structural adhesives such as DP8005 and DP8010 Blue is usually characterized using an overlap shear test. Substrates are bonded together with a controlled overlap and the adhesive is allowed to cure. After cure the adhesive bond is pulled in the shear mode at a constant rate and the peak force to break is measured. By convention an adhesive is considered structural if it is capable of achieving greater than 1000 psi break strength in the overlap shear test. To achieve this level of break strength the adhesive must have high adhesion strength to the substrates.

DP8005 and DP8010 Blue create structural (greater than 1000 psi overlap shear) bonds to low surface energy plastics without pre-treatment. Below are some representative overlap shear bond strength data for DP8005 and DP8010 Blue on common plastic substrates including LSE plastics. Note that with several substrates tested the substrate itself was not strong enough to support the 1000 psi load and the substrate failed before the adhesive-to-substrate bond did.



Bonding Strength of 3M™ Scotch-Weld™ Structural Plastic Adhesive DP8005 and 3M™ Scotch-Weld™ Structural Plastic Adhesive DP8010 Blue on some common plastics.



Bonding Strength of 3M™ Scotch-Weld™ Structural Plastic Adhesive DP8005 and 3M™ Scotch-Weld™ Structural Plastic Adhesive DP8010 Blue on HDPE after various environmental challenge conditions.

Because of their high bond strengths to untreated polyolefins, ease of use (in Duo-Pak cartridges with static mix nozzles) and favorable environmental characteristics, DP8005 and DP8010 Blue have met great success in bonding low surface energy plastics in a variety of applications. Typical applications include bonding of molded or thermoformed parts for interior and exterior fascia, liquid containers, decorative panels, appliance and sporting goods trim and accessories, protective equipment and electronic components wire potting and housings.

Hot Melt Adhesives:

Hot melt adhesives may also be used to bond lightweight thermoplastic pieces. These adhesives have the advantage of providing quick tack and handling strength, thus speeding production. These adhesives combine high heat resistance with relatively high strength and low creep. These products can provide benefits to manufacturers who can trade off heavy duty bonding for faster production speed in applications such as POP displays; sample boards and tabletop displays; exhibitor booths; foam inserts to carrying cases; fabric or paneling to foam; and molded reinforced plastic to fabric or fascia for furniture and automotive interiors.

Pressure Sensitive Adhesives:

Pressure sensitive is a unique category of adhesives in that they do not cure or undergo a chemical change when applied. Pressure sensitive adhesives are viscoelastic materials that exhibit both viscous (flow) and

elastic (resistance) properties at the same time. When the adhesive is put on the substrate typically in tape form and pressure is applied the adhesive makes immediate contact for initial adhesion but continues to flow onto the surface to achieve increased contact and a higher level of strength over time. One advantage of pressure sensitive bonding tapes is that the bond is immediate so there is no clamp or cure time. They are also unique in that you do not have to bond the adhesive to both substrates at the same time. The tape can be applied to the first substrate one day and to the second substrate the same day, the next day, or weeks later. This brings added convenience and can be a benefit for many applications including assembly line processes.

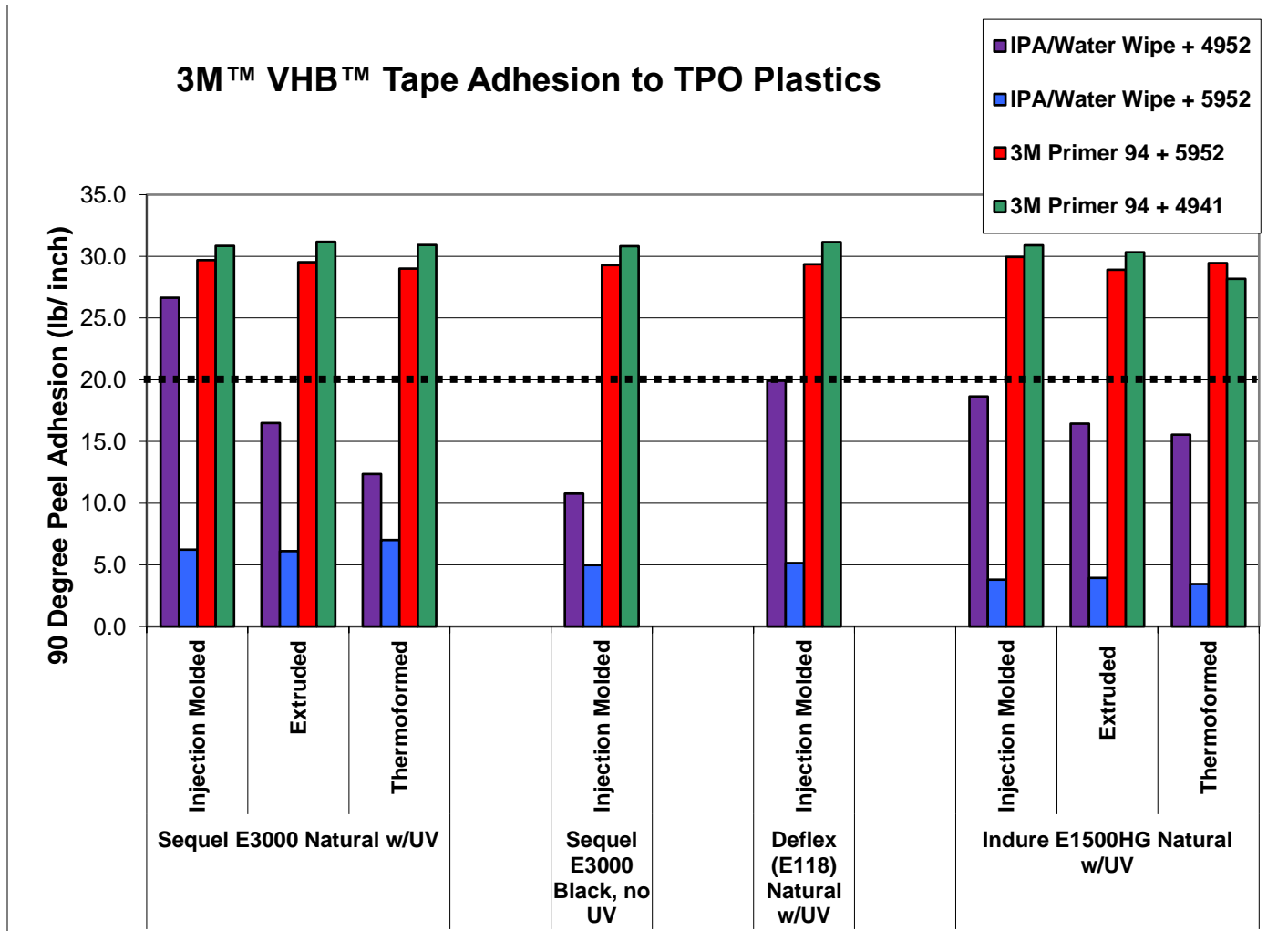
Acrylic pressure-sensitive adhesives often provide the best balance of adhesion and performance properties for many applications, including the type 300LSE Pressure Sensitive Adhesive family of products that have been developed to bond low surface energy plastics. 3M™ High-Strength Acrylic Adhesive 300LSE is a thin PSA designed specifically for bonding difficult LSE substrates such as polypropylene, TPO, and a variety of other plastics while providing excellent resistance to high temperatures and chemicals, and high peel strength. It also bonds well to metals and other more friendly substrates, thus providing a PSA bonding solution for applications such as durable graphic bonding, dissimilar material bonding, foam and rubber bonding, plastics assembly and more.

Very high strength bonding tapes are available and are used for a variety of applications previously reserved for mechanical fasteners or structural adhesives. These tapes have an acrylic foam construction and have viscoelastic characteristics throughout the product. The foam absorbs energy to provide high strength and relaxes stress to protect the bond. The tape allows, rather than fights, movement between parts. A high level of tape-to-substrate adhesion is required for the foam to allow relative movement of the parts without coming debonded at the tape-to-substrate interface.

3M VHB™ Tape LSE Series tapes are designed to adhere to PP, TPO, TPE, and composite substrates without the use of primer. Other acrylic foam tapes do not have high enough adhesion strength to LSE plastics without additional surface modification. Easy-to-use brush-on primer (e.g. 3M™ Primer 94) is available to give very high tape-to-substrate adhesion on some LSE plastics. For even lower surface energy plastics such as PE, flame, corona or plasma treatment is suggested prior to bonding.

Strength of pressure sensitive bonding tapes is typically characterized using a peel adhesion test. Below is 90-degree peel adhesion data for a variety of 3M™ VHB™ Tapes on four grades of TPO with different surface preparation techniques. Although required bond strength varies by application, typically an adhesion level of 20 lb/inch or greater in this test is desired for most general applications.

High strength bonding tapes are typically used for bonding panels to frames, bonding stiffeners to panels, and bonding decorative overlays and scuff and rub strips.



Summary

New tape and adhesive technologies that bond to LSE plastics offer increased efficiency, reduced costs, and improved design flexibility when using these versatile and popular plastics for manufacturing a variety of products. Examples include bonding thermoformed bumpers to metal; vehicle seats, toppers and accessories; binning strips; architectural panels; plastic lumber; signage; transport cases; protective armament, and many others.

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