Pressure-sensitive adhesive tapes for IVDapplications

Selecting the proper pressure-sensitive adhesive tape can guarantee product performance and can save production costs of IVD test strips.

BY PETER ILFENHAus, INGO NEUBERT, AND TED MEIGS

IVD test strips and biosensors are used in a ange of modern diagnostic applications such as blood glucose monitoring, pregnancy and fertility tests, and infectious disease detection. Such test strips are normally composed of several layers. The state-of-the-art assembly of bonding the different layers is accomplished by either printing heat-seal adhesives or using pressure-sensitive adhesive (PSA) tapes. One single test strip often contains various layers of tapes for laminating and marking. For example, in capillary cell biosensors, a spacer tape de.fines the height of the capillary cell, which is formed by die- or laser-cutting, while the lid of the capillary is made of another adhesive tape or a hydrophilic film.

PSA tapes offer diverse advantages for manufacturing IVD test strips and biosensors. They are easier and faster to apply, do not need any heat activation, which might damage the enzyme or other test strip components, and can generate a sufficient and well de.fined thickness in one step. Therefore, many capillary cell biosensor manufacturers prefer PSA spacer tapes.

However, if an IVD test strip manufacturer uses an inappropriate adhesive, oozing and adhesive buildup on machine parts during slitting can be an issue.[1] Oozing, or cold flow of the adhesive, can result in numerous problems. For example, if the adhesive oozes out of the edges of the test strips, the strips may stick to each other or the packaging. If the adhesive oozes into a biosensor's capillary channel, the channel geometry can change, the adhesive might cover and reduce the active enzyme area, or the adhesive could clog the capillary cell's venting hole. The eventual consequences can be inaccurate test results or defective test strips. Also, adhesive buildup can be an automation challenge for the machine builders and an issue for manufacturers since additional cleaning would be required, causing additional machine downtime and maintenance.

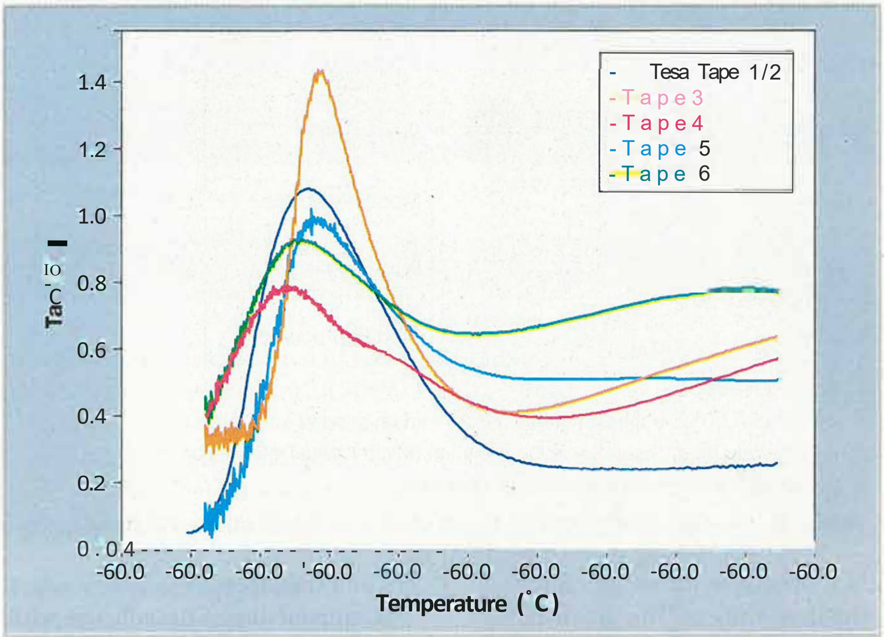

Figure 1. Dynamic mechanical analysis of pressure-sensitive tapes used in IVD test strips and biosensors.

The compatibility of the adhesive system with the test assay (or other parts of the test strip) and aging stability are thoroughly tested at an early stage in test strip development. Such prerequisites are well known by adhesive and tape manufacturers involved in the IVD industry, and are key considerations during raw material selectipn, product development, and manufacturing.

In contrast, adhesive buildup and manufacturing efficiency are sometimes tested at later stages in product development (e.g., if a new product is to be produced on a new manufacturing line). The possibility of adhesive buildup and its extent depend on the type and characteristics of the adhesive being used. Mitigating this issue could start with selecting and using

Type of Adhesive	Complexity of Formulation[1]	Compatibility[2]	Adhesion	Cohesion
Pure Acrylic	low	high	medium	high
Modified Acrylic	medium	medium	high	medium
Water-based Acrylic	medium	medium	medium	very low
Rubber-based	high	low	high	low

1. Based on the number and chemical variety of components
2. Exclusion of possible interaction based on complexity of formulation

Table I. Comparison of different types of adhesives.

	Product Design [backing; adh. coat weight]	Type of Adhesive	Peel Adhesion on PET1 [N/cm]	Static Shear Resistance2 [min]	Static Shear Deformationl [l,1m]
tesa Tape 1	50 µm PET; 2 x 15 gsm	Pure acrylic	2.2	> 10,000	45
tesa Tape 2	50 µm PET; 2 x 35 gsm	Pure acrylic	3.5	> 10,000	84
Tape 3	12 µm PET; 2 x 35 gsm	Pure acrylic	3.6	5,500	230
Tape 4	75 µm PET; 2 x 30 gsm	Modified acrylic	5.6	4,200	290
Tape 5	12 µm PET; 2 x 18 gsm	Pure acrylic•	2.6	2,100	385
Tape 6	90 µm PET; 2 x 20 gsm	Modified acrylic	2.5	10	> 2,000

1. acc. AFERA 5001
2. acc. AFERA 5012, adhesion area 13 x 20 mm on grinded steel plates
3. tesa test method: Static Shear Deformation (Micro Creep Deformation)!,<;
4. Probably pure acrylic, not analytically confirmed

Table II. Characterization of PSA tapes used in IVD test strips and biosensors.

PSA tapes at an early stage in test strip development. This article provides background information, study results, and recommendations to consider when testing and selecting PSA tapes for IVD test strips.

Pressure-Sensitive Adhesives and Tapes for IVDs

In general, four different types of PSAs are used in IVD test strips and biosensors: pure acrylic, modified acrylic, water-based acrylic, and rubber-based adhesives. Pure acrylic adhesives consist of a copolymer, which is made of monomers of different acrylic derivates. Modified acrylic adhesives contain additional resins to increase adhesion. Water-based acrylic adhesives are dispersions, which contain emulgators. Rubber-based adhesives are composed of elastomers/polymers, resins, oil or softeners, and stabilizers.[1,2]

Compatibility of the adhesive with the IVD assay depends on the complexity of the adhesive formulation, or the chemical diversity of the adhesive components. As a general rule, adhesives with less complex formulations and possible impurities have a lower propensity for interactions with test components and tbus higher compatibility levels. In addition, a higher number of raw materials increase the risk of subsequent product changes (e.g., if raw material suppliers modify their products).

Adhesion, the bonding strength of the adhesive to the substrate, and cohesion, the adhesive's inner strength, are the most important characteristics of an adhesive used in IVD test strips. On one hand, they determine the test strip's integrity and performance; on the other band, they safeguard the stability and efficiency of the production process. The adhesive tape must bond to the other layers of the test strip immediately and reliably. The initial and permanent bonding strength depends on not only the adhesive properties but also other factors, such as the substrate materials, their polarity, roughness, and ambient temperature. The bonding strength to the substrate increases after the initial bonding and reaches a plateau over time. Therefore, while the initial adhesion of tbe PSA tape must be sufficient to guarantee a stable production process and the test strip's integrity, it does not need to increase further.

This point is very important when selecting the proper adhesive tape for IVD applications, since adhesion and cohesion evolve in opposite directions and it is expected that the

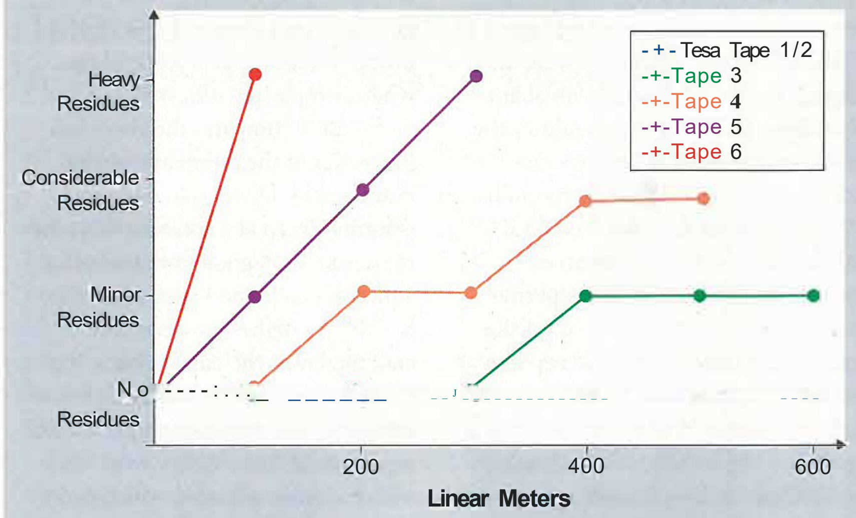

Figure 2. Adhesive buildup during slitting with the Kinematic Matrix 2501 Module.

higher the cohesion, the lower the tendency for adhesive buildup.[2] The cohesive properties of an adhesive depend on the adhesive formulation, the molecular weight of the polymers, and the degree of cross-linking. The higher the molecular weight and the longer the polymer chains, the higher tbe inter-molecular entanglement and cohesion. Cross-linking, or the forming of bonds between the polymer chains, also increases cohesion.

Table I evaluates and compares the characteristics that determine the compatibility and efficient production of different adhesive types. The comparison reveals tbat acrylic adhesives offer advantages compared with rubber-based adhesives with respect to compatibility. While the cohesion of rubber-based adhesives is low, pure and modified acrylic adhesives can cover nearly the complete range of the adhesion and cohesion spectrum. Water-based acrylic adhesives with a limited adhesive-cohesive profile are used for special applications, such as inline printing.

Table I shows only those trends and limitations that are valuable for an initial selection of PSA tapes, and simplifies the view on adhesives. In reality, the adhesive and cohesive properties of all types of adhesives can vary over a broad range. The properties can be adjusted and balanced in various ways, such as the selected monomers and their polarity, the type of polymer, the molecular weight of the polymer, cross-linking, or the utilization of additives (e.g., tackifiers and plasticizers). Testing the level of adhesion is done by conducting peel adhesion on different materials such as steel or polyethylene terephthalate (PET). Cohesion is measured by static shear resistance tests and/or shear deformation tests.[1,3-6]

Tape Characteristics

To assess in detail the buildup of adhesive residue during slitting and to correlate the buildup to PSA tape characteristics, a number of commercially available double-coated tapes used to manufacture IVD test strips were examined. This study focused on PSA tapes with pure and modified acrylic adhesives since they dominate the market for IVD test strips and biosensors. Table II summarizes the characteristics of the different tapes.

Table II reveals that the peel adhesion on PET varied only slightly for most products, except Tape 4. The results of the peel adhesion studies depend on the type of adhesive, the adhesive coat weight, and the stiffness (or thickness) of the backing material. Therefore, peel adhesion values between two and four N/cm are presumably sufficient in most cases to ensure a stable manufacturing process and product integrity for IVD test strips. (Even if the initial adhesion is too low for a stable process, a slight increase in lamination temperature and pressure can rectify this problem.) This level of peel adhesion can be reached with pure acrylic adhesives, which offer advantages with respect to compatibility. The cohesion properties of pure acrylic adhesives also cover a broad range as verified by the shear study results. Tapes 1 and 2 by tesa SE (Hamburg, Germany), which are based on the same adhesives that are specially designed for IVD test strip applications, show a very high cohesion compared with the other tapes.

The PSA tape properties were also investigated using dynamic mechanical analysis (DMA), which allows the measurement of an adhesive's viscoelastic properties. Storage modulus G', loss modulus G", tan 8 (G"/G'), and viscosity were the properties analyzed by DMA. These properties were determined· as a function of the temperature (temperature sweep at a constant frequency) or as a function of the frequency (frequency sweep at a constant temperature). DMA enables a general prediction regarding the adhesion properties and the performance of an adhesive in production processes, and is also a useful tool when comparing adhesives.

Figure 1 compares the viscoelasic properties of the different tapes as examined by DMA (tan 8 in temperature sweep at a constant frequency of 0.1 rad/s). A good indicator of an adhesive's cohesion is the tan 8 value (G"/G') at higher temperatures. In general, the lower the tan 8 value at higher temperatures, the higher the adhesive's cohesion. The graphs for tapes 1 and 2 are identical because they were made with the same adhesive, which had a lower tan 8 value at temperatures higher than 50° C compared with the other products (see Figure 1). The results of the DMA corresponded with those of the shear studies.

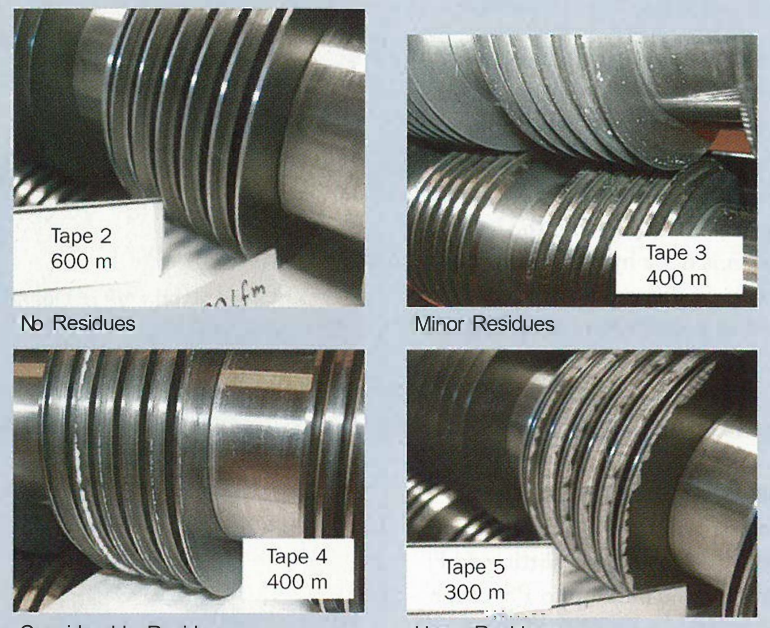

Figure 3. Photographs of adhesive buildup observed in this article.

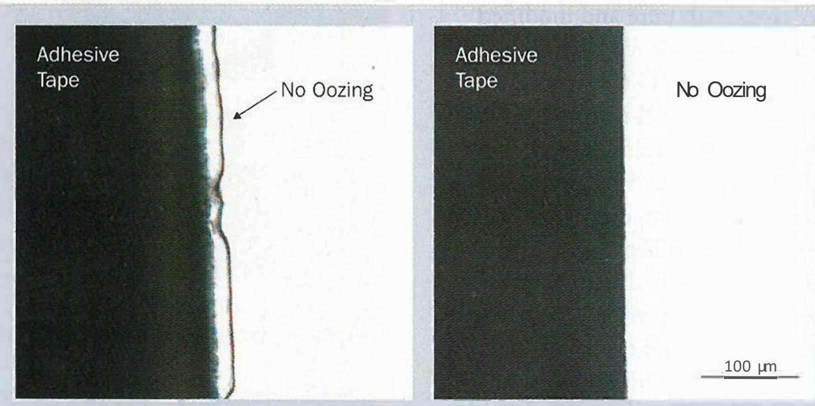

Figure 4. Microscopic pictures (100x) of tapes 2 and 5 after oozing tests.

Adhesive Residue During Slitting

The PSA tapes were tested in slitting trials using a Matrix 2501 Module by Kinematic Automation (Twain Harte, CA). The adhesive buildup from endless slitting runs was determined every 100 meters on a semi-quantitative basis. No processing aids, such as knife oil, were used during the trials. The slitting was stopped after either heavy adhesive buildup on the cutting blades or after reaching 600 meters. Figure 2 gives an overview of the results, and the photographs in Figure 3 show the adhesive buildup observed in this study.

The results confirmed that the higher the cohesion, the lower the adhesive residue. Surprisingly, the significant increase of the adhesive coat weight in tesa tapes 1 and 2 from 2 x 15 gsm to 2 x 35 gsm did not cause greater adhesive buildup. This result confirmed that the high cohesive strength of the tesa tapes is sufficient to avoid adhesive buildup. In addition, tapes 3 and 4, with a higher adhesive coat weight than tapes 5 and 6, exhibited comparatively lower levels of adhesive buildup. Thus, the study concluded that the cohesive characteristics affect adhesive buildup more than the tape's adhesive coat weight.

It is commonly believed that a low adhesive coat weight or a decrease in coat weight reduces the risk and extent of adhesive buildup. However, such an approach to decreasing adhesive coat weight in order to reduce adhesive buildup does not get to the root of the problem (i.e., adhesive formulation) but only optimizes superficially. This approach might even result in additional adhesion-related problems during manufacturing or product-related problems with regard to IVD test strip stability or integrity when applied to challenging or rough surfaces.

This dilemma and the results of this study showed that the key success factor for a stable and efficient IVD test strip production lies in carefully selecting a PSA tape with well-balanced adhesion and cohesion

The Adhesive Nightmare: A Machine Builder's View

By Ted Meigs

Adhesive buildup can be the single biggest automation challenge for machine builders and the single biggest headache for IVD manufacturers. Mitigating this problem can have a dramatic effect on product yield and manufacturing efficiency.

The labor-intensive process of cleaning adhesives from machine components is a tedious and time-consuming task. This process involves manual scraping and using solvents that are neither human nor product friendly.

Cleaning solvents mixed with adhesives creates additional challenges. This combination has a viscosity that allows the sticky solution to permeate into places on a machine that should not otherwise be exposed to adhesives. Machine components, such as vacuum ports and precision mechanisms, can plug and gum up to the extent that major part maintenance will frequently be required.

Not a One-Size-Fits-All Solution

Creative attempts at adhesive removal range from dry ice blasting and ultrasonic cleaning to a hazmat extravaganza of manual and labor-intensive tedium. The problem with automated attempts to clean adhesives is that these processes are proportionally as hard on the parts being cleaned as they are effective at cleaning, which can lead to increased part maintenance and replacement costs.

IVD manufacturers must recognize this problem and work with their suppliers and automation partners early in the product development process. A manufacturer's scientist who focuses on new product development and technological breakthroughs is probably not an automation expert. In some cases, it may be too late in the process to make fundamental changes to the product due to time or validation constraints.

Choosing the Right Adhesive Is the Key

Designing for adhesive mitigation is critical. Proper clearances, selection of materials, coatings, and quick replacement of parts subject to adhesive buildup are all very important. Proper machine design for adhesive mitigation can mean stopping to clean once every few hours instead of every 20-40 minutes. Choosing the right adhesive can also extend intervals between cleanings to days or even weeks. An IVD manufacturer with a 24/7 production operation can imagine the negative impact an inappropriate adhesive can have.

Designing IVD products for manufacturability and automation is a key to success. Optimizing the materials selected for products is as important as product geometry. In many cases, the variety of material choices available for most products is plentiful.

properties (i.e., an adhesive specially developed for this application). As with any application and final test strip design, the IVD manufacturer must determine the suitability of a specific tape.

Oozing Tests and Results

The tendency for oozing, or cold flow, is a consequence of the PSA's viscoelastic behavior. In general, the higher the cohesion, the lower the tendency for cold flow. The tendency for oozing was tested using tapes 2 and 5. The 2.5 x 2.5-cm tape samples were applied to a release liner, loaded with 10 kg weight, and stored at 70° C for 14 days. The microscopic images of the samples after storage show oozing in direct correlation to the adhesive's cohesion (i.e., very clearly for Tape 5, but almost none for Tape 2) (see Figure 4). In addition, the image of Tape 5 reveals another issue related to oozing during manufacturing: the tape's contours become indistinct due to the adhesive seeping over the edge. The lack of clarity at the edge of the tape means that the die-cut contours can no longer be used as a register for positioning test strip components during lamination (e.g., when positioning a capillary die-cut onto a bottom film carrying the enzymes and electrodes), and severely affects the reproducibility of manufacturing processes.

Conclusion

The selection of adhesive tapes is a critical step in developing new IVD test strips. This selection should be based on product design-related properties, such as compatibility, stability, thickness tolerances, etc., but must also consider manufacturing-related characteristics. In this respect, while adhesion is obviously the first characteristic to be considered, cohesive characteristics are sometimes neglected during the initial selection stage. The result is that a series of optimization cycles with changes in the tools, the process, or even the adhesive tape are required to reduce adhesive buildup or oozing. Under the pressure of a tight product launch schedule, such changes can become an adhesive nightmare.

Selecting the right tape with the right adhesive at an early stage in IVD test strip development reduces time-to-market and provides the basis for a stable and efficient production. The balance between adhesive and cohesive characteristics and customized tape designs is a key success factor. Pure acrylic adhesives offer an adhesion level sufficient for most test strip substrates and advantages with respect to cohesion (i.e., a lower risk of adhesive buildup). In addition, they offer advantages with respect to compatibility.

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