

APARATURA BADAWCZA I DYDAKTYCZNA

Adhesion measurement of pressure-sensitive adhesives

ZBIGNIEW CZECH¹, DOMINIKA SOWA¹, AGNIESZKA KOWALCZYK¹, JOLANTA ŚWIDERSKA²

¹INSTITUTE OF CHEMICAL ORGANIC TECHNOLOGY, WEST POMERANIAN UNIVERSITY OF TECHNOLOGY, SZCZECIN, POLAND,

²NON-PUBLIC HEALTH CENTER, SZCZECIN, POLAND

Keywords: adhesion, peel adhesion, measurement methods, pressure-sensitive adhesives (PSA)

ABSTRACT

The term pressure-sensitive adhesive (PSA) has a very precise technical definition and was dealt with extensively in the chemical literature. Pressure-sensitive adhesives (PSA) are nonmetallic materials used to bond other materials, mainly on their surfaces through adhesion and cohesion [1]. Adhesion and cohesion are phenomena, which may be described thermodynamically and chemically, but actually they cannot be measured precisely. It was shown [2] that the most important bonding processes are bonding by adhesion and bonding with pressure-sensitive adhesives. A theoretical treatment of adhesion in terms of intermolecular interaction is not just confined to bond energies; other important factors are the number of contact points of the interacting atoms or molecules, intermolecular distances, the mobility of atomic groups and the structure of neighboring matter. Adhesion on the area of PSA is described by mechanical interlocking, adsorption or thermodynamic theory, electrostatic theory, chemical bonding theory, diffusion theory, adhesive effect of thin liquid films and theory of weak boundary layers. Adhesion of PSA plays the significant role by the application of self-adhesive materials in different industry branches [3].

Pomiar adhezji klejów samoprzylepnych

Słowa kluczowe: adhezja, adhezja przy oddzieraniu, metody pomiaru, kleje samoprzylepne

STRESZCZENIE

Pojęcie klej samoprzylepny jest bardzo precyzyjnie zdefiniowane i obszernie opisane w fachowej literaturze chemicznej. Kleje samoprzylepne to niemetaliczne materiały, służące do łączenia powierzchni różnorodnych materiałów poprzez adhezję oraz kohezję [1]. Adhezja oraz kohezja są zjawiskami, które można stosunkowo dokładnie opisać za pomocą termodynamiki oraz znanych reakcji chemicznych, lecz ich pomiar nie pozwala na daleko idącą precyzję. Udowodniono, że najważniejszymi procesami, prowadzącymi do bardzo trwałych połączeń, są połączenia związane z adhezją klejów samoprzylepnych [2]. Teoretyczne podstawy wielu teorii adhezji w połączeniu z oddziaływaniami energetycznymi są bardzo ważne, ale najważniejszymi parametrami zjawiska adhezji są: wielkość sklejaney powierzchni, odległość intermolekularna sklejaney powierzchni, ruchliwość, polarność oraz reaktywność grup funkcyjnych kleju samoprzylepnego. Adhezja klejów samoprzylepnych jest wyjaśniana i opisywana poprzez adhezję mechaniczną, adsorpcję, zależności termodynamiczne, teorię elektrostatyczną, teorię wiązań chemicznych, dyfuzję, teorię cienkich warstw granicznych oraz zwilżalność sklejaney powierzchni przez warstwę polimeru o właściwościach samoprzylepnych [3].

1. PRESSURE-SENSITIVE ADHESIVES

The term pressure-sensitive describes adhesives, which in the dry form are aggressively and permanently tacky at room temperature and firmly adhere to a variety of dissimilar surfaces upon mere contact, without the need of more than finger or hand pressure [1]. Pressure-sensitive adhesives possess adhesion, required for bonding and debonding, and cohesion necessary against debonding. Adhesion is characterized by tack and peel, whereas cohesion is described by shear resistance, and partially by peel. The special balance of these properties, the adhesion/cohesion balance, embodies the pressure-sensitive character of the adhesive. The efficiency of the bonding process is related to the adhesive's ability to exhibit viscous flow. In order to achieve peel adhesion the bonding stage involves some dwell time. During this time the adhesive must flow in the absence of any externally applied forces. The more liquid-like the behavior of the polymer under these conditions, the more pronounced the degree of bond formation. A proper balance between high tack, peel adhesion, and high cohesion is necessary in most cases. The behavior of any pressure-sensitive adhesive can be reduced to three fundamental and interconnected physical properties: tack, adhesion (peel adhesion), and shear resistance (cohesion). A clear understanding of each property and term is essential.

PSA are widely used materials in our daily life, such as in one-sided, double-sided or carrier free mounting tapes, sign and marking films, labels, protective films, splicing and masking tapes, plasters, OP-tapes, biomedical electrodes and self-adhesive hydrogels [2]. Polymers employed as PSA have to fulfill partially contradictory requirements; they need to adhere to substrates, to display high shear strength and peel adhesion, and not leave any residue on the substrate upon debonding. In order to meet all these requirements, a compromise is needed. When using PSA there appears another difference with wet adhesives, namely the adhesive does not change its physical state because film forming is inherent to PSA [3].

The fundamentally properties, which are essential in characterizing the nature of PSAs comprise: tack, peel adhesion, and shear strength. The first (tack) measures the adhesive's ability to adhere quickly, the second (adhesion) its ability to resist removal through peeling, and the third (cohesion) its ability to hold in position when shear forces are applied [4].

There are two meanings of the term "adhesion" [5]. On the one hand, adhesion is understood as the process through which two bodies are attached to each other when brought together. In this sense adhesion characterizes the sum of all intermolecular and electrostatic forces acting across the interface. On the other hand, we

may examine the process of breaking the already adhesive in contact. In this case adhesion is the force, or the energy, required to separate the two bodies, often called "practical adhesion" or "adherence".

Adhesion is a state in which two surfaces are held together by interfacial forces. Many theoretical models of adhesion have been proposed, which together are both complementary and contradictory. The most important will now be described:

1.1 Mechanical interlocking

Mechanical adhesion is adhesion that exists between surfaces in which the adhesive secures the adherents by means of interlocking forces. The theory states that adhesion only occurs if the surface has roughness-comprising cavities, pores, etc. - into which the adhesive can flow. The fact that smooth surfaces can be bonded contradicts the theory [6].

1.2 Adsorption thermodynamic theory

This kind of adhesion could be calculated from the magnitude of the interfacial free energies or work of adhesion. Provided that this process is reversible, this work must be expended in order to separate the two surfaces. Because this condition is never satisfied in practice, in reality a number of other factors must be added: the separation process takes place at a finite rate and thus kinetic processes have a part to play. Here, adhesion is not solely determined by interactions at the interface of adhesive and adherent, rather by processes that occur deep inside them. Although the adsorption or thermodynamic theory is not free from contradictions, it is certainly the most widely used approach to adhesion mechanism at present [7].

1.3 Electrostatic theory

This theory proposes that an electron transfer mechanism between the substrate and the adhesive - one being more electronegative than the other - results in the formation of an oppositely charged electrochemical double layer. The strength of the adhesive bond is thought to be to the attraction between the charges on the opposite sides of the interface [8].

1.4 Chemical bonding theory

The formation of the interface of chemical bonds between the molecules of the substrate and ad-

hesive usually results in high adhesive strength. Ideally, these covalent bonds would be formed between polymer chain molecules firmly anchored in the bulk of the substrate or adhesive. However, in practice, interaction to such an extent is not possible. One of the most important adhesion fields involving interfacial chemical bonds is the use of adhesion promoter molecules to improve the joint strength between adhesive and substrate [9].

1.5 Diffusion theory of adhesion

The diffusion theory can be considered as a cross between the wetting theory and the mechanical interlocking theory. It was developed primarily to explain polymer-to-polymer adhesive systems. According to this theory the polymer chains, due to their mobility, diffuse into each other across the interface and molecularly interlock. Since diffusion is a time-dependent process, the strength of the adhesive bond increases with time. The joining of plastics, which can be softened with solvents and bonded together, can be taken as an example [10].

1.6 Adhesive effect of thin liquid films

The bond formed between two rigid, flat sheets by intermediate film of liquid has extraordinarily high tensile strength but very poor shear strength. This theory forms a good basis for describing the adhesion of pressure-sensitive adhesives [11].

1.7 Theory of weak boundary layers

According to this theory, the failure of an adhesive joint at the interface of adhesive and substrate never occurs in practice. It says that the break always occurs as a result of cohesive failure within a weak boundary layer that spans the interface. The reason for the lower cohesive strength is alteration or modification of the adhesive and/or adherents due to presence at the interface of impurities or short polymer chains. Although this type of case has been demonstrated in practice, the general validity of the weak boundary layers theory has been called into question [5].

2. EVALUATION OF THE PEEL ADHESION

To determine the adhesiveness property, various testing methods are suggested, for example, peel adhesion measurement under 180° and under 90° [12].

2.1 Measurement of peel adhesion under 180°

The peel adhesion is the force required to remove a coated flexible pressure-sensitive adhesive sheet material from a test panel measured at a specific angle and rate of removal. For 180° peel measurements (AFERA 4001) the results depend on the face stock material [13].

A sample of PSA-coated material 1-inch (about 2.5 cm) wide and about 5-in (about 12,7 cm) long is bonded to a horizontal target substrate surface of a clean steel test plate at least 12,7 cm in firm contact. A 2 kg hard rubber roller is used to apply the strip. The free end of the coated strip is doubled back nearly touching itself so the angle of removal will be 180°. The free end is attached to the adhesion tester scale.

The steel test plate is clamped in the jaws of tensile testing machine Zwick 1445, which is capable of moving the plate away from the scale at a constant rate of 300 mm per minute. The scale reading in Newtons is recorded as the tape is peeled from the steel surface. The data is reported as the average of the range of numbers observed during the test. The peel adhesion test of pressure-sensitive adhesives was conducted with two to three identical samples (Fig. 1). The given result is an arithmetic average from the available peel adhesion results.

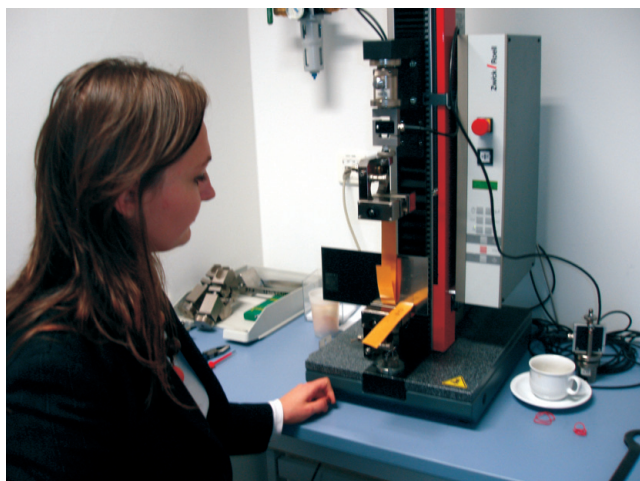


Figure 1 Peel adhesion on steel according to AFERA 4001 under angle 180°

Rysunek 1 Pomiar adhezji pod kątem 180° wg metody AFERA 4001

The peel adhesion and the removability are judged according to the following ratings and recorded:

- good-samples that are removed from the test substrate without damaging or leaving residue on

the test substrate;

- tear-samples that display too high a peel adhesion to the test substrate, causing test substrate and/or polyester foil backing to tear or delaminate at any peel rate;
- cohesive failure-samples that leave adhesive residue on both the polyester film backing and the test substrate (Fig. 2).

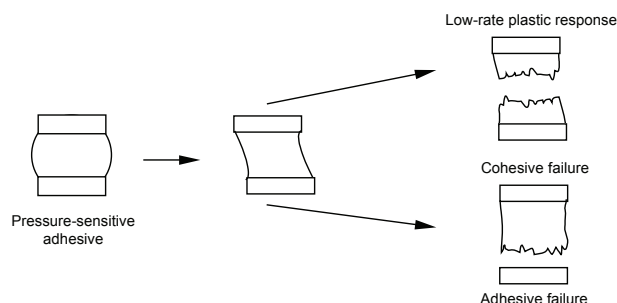


Figure 2 Cohesive failure in PSA layer
Rysunek 2 Pęknięcie kohezyjne w warstwie kleju samoprzylepnego

2.2 Measurement of peel adhesion under 90°

The tape sample to be tested under 90 degree consists of a backing laminated to or coated with a pressure-sensitive adhesive (Fig. 3).

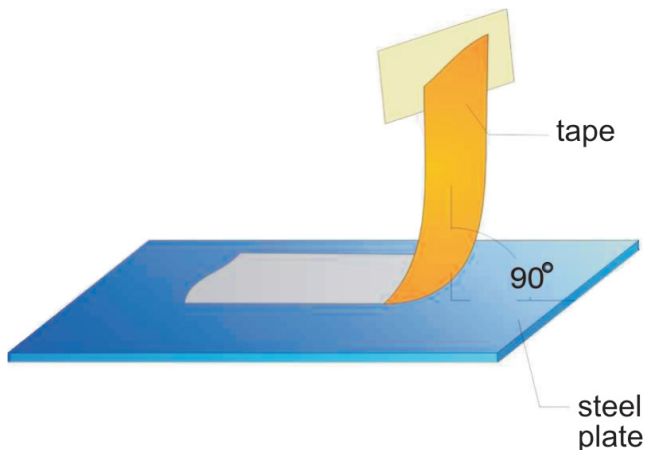


Figure 3 Peel adhesion test under angle 90°
Rysunek 3 Pomiar adhezji pod kątem 90°

A stainless steel test panel at least 5 cm by 25 cm is used as the substrate from which the sample is peeled. The last 2,5 cm of the length of the panel is covered with masking tape. Strips of tape samples 2,5 cm by 25 cm are adhered by way of the pressure-sensitive adhesive to one major surface on the stainless steel test panel such that the end of the sample overlies the masking tape. The sample of tape is rolled twice with 4,5 kg roller

to firmly bond it to test panel. The major surface of the test panel not bearing the tape sample is adhered to the surface of peel adhesion tester by means of a double-coated tape. One end of the test sample is separated from the masking



Figure 4 Peel adhesion measurement on steel under angle 90° according to AFERA 4001
Rysunek 4 Pomiar adhezji na płytce stalowej pod kątem 90° wg metody AFERA 4001

tape by hand and peeled at a rate of 305 mm/min through a distance of 25 cm at a peel angle of 90 grade on special adapter (Fig. 4) on the testing machine. The initial 2,5 cm of peel data is discarded. The average peel force measured over the remaining peel length is recorded.

3. CONCLUSIONS

Adhesion measured as peel adhesion of pressure-sensitive adhesives is a very important and significant main parameter of self-adhesive materials, such as mounting tapes, splicing tapes, labels, protective films, sign and marking films and different medical products. Adhesion, other known as peel adhesion is dependent on contact time between PSA layer and surface of bonded substrates and is normalized according international institutes. Peel adhesion is responsible property for all industrially applications.

The adhesion level of PSA and self-adhesive materials, measured as peel adhesion values, are function of adequate adhesion methods. Peel adhesion measured under 180 degree and 90 degree are the most popular adhesion measurement methods in the PSA industry and technology.

REFERENCES

- [1] Villa G. J., Die Geschichte der selbsthaftenden Klebstoffe, Adhäsion (1977), 10, 284-288.
- [2] Benedek I., Developments in Pressure-Sensitive Products, Ed. by Istvan Benedek, Taylor & Francis a CRC Press Book, New York (2006).
- [3] Czech Z., Vernetzung von Haftklebstoffen auf Polyacrylatbasis, Ed. by Technical University of Szczecin (1999).
- [4] Czech Z., Kowalczyk A., Madejska E., Głuch U., Ortyl J., Adhesion of Pressure-Sensitive Adhesives (PSAs), Coating 5 (2011) 32-35.
- [5] Lim D. H., Kim J. J., General Performance of Pressure-Sensitive Adhesives in Pressure-Sensitive Design, Theoretical Aspects, I. Benedek [editor]. Theoretical Aspects Volume 1, VSP. Leiden, Boston (2006) 291-317.
- [6] Krenceski M. A., Johnson J. F., Temin S. C., Chemical and Physical Factors Affecting Performance of Pressure-Sensitive Adhesives, Macromol. Chem. Phys. C26 (1) (1986) 143-182.
- [7] Druschke W., Adhäsion und Tack von Haftklebstoffen, Adhäsion 5 (1987) 29-32.
- [8] Zorll U., Elektrostatische Adhäsionswirkunge, Adhäsion 5/6 (1976) 142-149.
- [9] Druschke W., Adhäsion und Tack von Haftklebstoffen, Adhäsion 6 (1987) 26-34.
- [10] Zorll U., Fortschritte in der Adhäsionmeßtechnik, Adhäsion 3 (1976) 69-74.
- [11] Springer J., Förster F., Theorien zur Haftung stromlos abgeschiedener Metallschichten auf Polymeren, Metalloberfläche 38 (1984) 482-486.
- [12] Czech Z., Butwin A., Głuch U., Madejska E., Pressure-Sensitive Adhesives (PSAs), Coating 10 (2010) 34-38.
- [13] Zosel A., Journal of Adhesion, The effect of bond formation on the tack of polymers, 11 (1997) 1447-1457.