Prosimy cytować jako: Inż. Ap. Chem. 2015, 54, 1, 12-13

Izabela IRSKA[1], Adrian Krzysztof ANTOSIK[2], Elżbieta PIESOWICZ[1], Zbigniew CZECH[2]

e-mail: izabela.irska@zut.edu.pl

[1] **Institute of Materials Science and Engineering, Faculty of Mechanical Engineering and Mechatronics, West Pomeranian University of Technology, Szczecin**

[2] **Institute of Organic Chemical Technology, Faculty of Chemical Engineering, West Pomeranian University of Technology, Szczecin**

Usability testing of water-soluble pressure-sensitive adhesives to labels

Introduction

An adhesive is any substance that, when applied to the surface of material, binds the surfaces together and resists separation. The basic ingredients are adhesive firming agents (binder), solvents, adhesion enhancing agents (coalescing agents), wetting agents, modifiers and stabilizers [*Gierenz and Karmann, 2001*]. There are many criteria for the classification of adhesives, although no one classification is universally recognized. Adhesives can be classified on the basis of chemical composition, source, function, physical form, mode of application and setting [*Ebnesajjad, 2008*].

Pressure-sensitive adhesives (PSA) are a special class of materials which in the dry form are aggressively and permanently tacky at room temperature. They easily adhere to any surface upon light pressure, in a short contact time [*Sowa et al., 2014*]. PSA represent a system that actually dates back to the invention of the self-adhesive articles in 1935 when *R. Statnon Avery* produced the first coating unit using a wooden cigar box with two holes cut in the bottom [*Czech, 2004*].

Due to many advantages PSA are being used for a wide range of self-adhesive materials such as self-adhesive labels, tapes, protective and decorative films [*Czech et al. 2013*].

According to the synthesis methods, pressure-sensitive adhesives can be divided into three groups: solvent-soluble (applied from solvent solutions) adhesives, water-soluble (applied from water dispersions) adhesives and hot-melt (solvent-free) adhesives [*Czech et al., 2011*]. Growing environmental awareness force to seek the replacement of solvent-soluble adhesives by solvent-free or water-soluble adhesives [*Rowitsch et al., 2014*]. Hence, water-soluble adhesives have existed for several decades, interest of them growing substantially [*Garret et al., 2000*]. Water-soluble adhesives offer several advantages, such as good adhesion to polar substrates, good heat and aging resistance. They also can be easily removed and are environmentally friendly [*Czech et al., 2011*].

Pressure-sensitive adhesives are widely used in packing industry to produce self-adhesive labels. Self-adhesive labels have a lot more advantages than other labeling techniques. They are cheap, easy to apply and have very good aesthetic qualities. Type of used adhesive depends on the package destination and the label material. Such adhesives must comply with the standards imposed by sector of returnable bottles and recyclable packaging materials. Label is exposed to a variety of factors such as: temperature changes, humidity and mechanical stress. For example, should not peel off when is exposed to the humidity, but must by easily separable from the package during normal cleaning processes.

Use of water-soluble adhesives in packing industry will offer benefits in terms of environmental protection and reduce costs.

To simplify the usability testing of water-soluble pressure-sensitive adhesives, three-step scale has been developed. In this work presented method was employed to evaluate the usefulness of adhesives for labels.

Materials and methods

In the present study the acrylic water-born adhesive was used.

As a model of label three different types of materials: paper, wax paper and polyethylene terephthalate (PET) were used. To evaluate the adhesion to surface material the following substrates were used: polyethylene terephthalate (PET), glass, and steel.

In order to study the usefulness of water-soluble adhesives to labels, adhesion to substrate and peel off time for each sample were tested. Each reported value is an average of seven test specimens.

Water-soluble adhesives adhesion to substrate

Water-born adhesives adhesion was tested using *Zwick-Roell Z1* machine according to international standard *Association des Fabricants Europeens de Rubans Auto-Adhesifs* (AFERA) 4001 procedures. Tape (25 mm width and 60 mm length) with about 60 g/m^2 coat weight of adhesive layer was adhered to substrate and pressed. After keeping it for 20 min. at room temperature, tape was peeled off at an angle of 180˚ at 300 mm/min. Depending on the value of adhesion; each tested sample was assigned to the appropriate value in accordance with the Tab. 1.

Tab. 1. Adhesion to substrate

Adhesion [N]	Assigned value
0÷4	1
4÷5	2
6÷8	3
8÷10	4
>10	5

Labels peel off time in water

On the model of label (paper, wax paper or PET film) with an area of 500 mm^2 (10 × 50 mm) a uniform layer of water-born adhesive (60 g/m^2) was applied. Obtained model of label was adhered to the test surface (with pressed). After 10 minutes, investigated sample was introduced at an angle of 90˚ to glass reactor with water (water temp. 20˚C). Time needed to peel off the label without mechanical intervention was measured. All tested surfaces were checked in terms of residual fragments of adhesives or labels. Obtained results were assigned to appropriate numerical values (Tab. 2).

Tab. 2. Peel off in water

Peel off time			Assigned value	Appearance
Paper label [min]	Wax paper label [min]	PET label [min]		
> 13	> 60	>960	0	Label adhere to the surface
11÷13	45÷60	780÷960	1	Label adhere to the surface
11÷13	45÷60	780÷960	2	Label fall off leaving adhesive residue on the surface
11÷13	45÷60	780÷960	3	Label fall off leaving no adhesive residue on the surface
9÷11	25÷45	600÷960	4	Label fall off leaving no adhesive residue on the surface
< 9	< 25	< 600	5	Label fall off leaving no adhesive residue on the surface

Usefulness of water-soluble adhesives to labels

The values assigned to the adhesion of water-soluble pressure-sensitive adhesive and peel off time of tested label were used to develop three-step scale, assessing the usefulness of adhesive to labels. Usefulness of water-born adhesives to labels is determined by the sum of the values obtained in both measurements. If score of the sample is in the range from 1 to 3 tested adhesive has to week adhesion to the substrate

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surface, in consequence is not suitable to use as an adhesive to labels. If the sum of the measurements is less than 8, the usefulness of adhesive is determined by value of the adhesion and according to the proposed scale must be higher than 3. Adhesives which will receive the total score 8 and higher, show a high adhesion to the substrate, at the same time, under the appropriate conditions they dissolve leaving no adhesive residue on the surface. These types of adhesives can be successfully used for combining labels with packing materials. Suitable values are assigned to the descriptive assessment of adhesives usefulness and listed in table 3.

Tab. 3. Rating scale

Sum off assigned values/ Rating scale	Rating of adhesive usefulness
1÷3	Adhesive is not suitable for use as an adhesive to labels.
4÷7	One of the studied parameters (or both) have a low value. The adhesive can be applied to the labels if the adhesion is higher than 3.
8÷10	Adhesives with very good properties to labels.

Results and Discussion

The results of adhesion strength of acrylic water-born adhesive to different substrates (PET, glass, steel) are summarized in Fig. 1. It was determined that, adhesion to the PET surface is lower than 3 N, what corresponds due to the proposed rating scale to 1. For the other tested substrates, glass and steel adhesion exhibit values of 14.44 N and 20.20 N, respectively. According to the Tab. 1 corresponding value of adhesion for both substrates, glass and steel is 5.

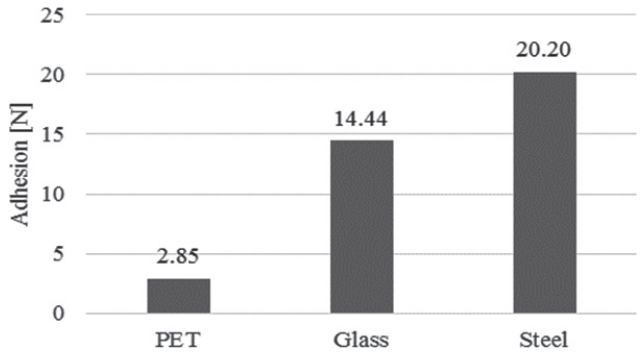

Fig. 1. Adhesion to substrate

Peel off time of all used types of labels is presented in Tab. 4. According to expectations, the shortest peel off times were obtained for labels made of paper and wax paper. The slowest adhesive dissolution was observed when PET label was used. This fact is connected with water permeability of used materials. If label was made from water-permeable material (paper or wax paper), water soak through the adhesive layer, dissolve adhesive and the label can be easily peeled. Label made from PET is not readily permeable and peel off time is very long (over 15 h). These may suggest that the PET label can also be removed by water but have different peel mechanism than water-permeable materials. In these case water is introduced to the adhesive along the edges of the label. In accordance to the established procedure obtained values of peel off time were assigned to appropriate numerical values from Tab. 2.

Tab. 4. Peel off time in water and corresponding numerical value

Surface	Peel off time					
	Paper label [h]	Corresponding value	Wax paper label [h]	Corresponding value	PET label [h]	Corresponding value
PET	00:11:21	4	00:29:14	4	15:10:16	3
Glass	00:10:42	4	00:28:10	4	12:03:56	4
Steel	00:13:05	3	00:31:42	4	15:23:53	3

According to procedure described above, the usefulness of tested adhesive in relation to three different surfaces (PET, glass and steel) and three different labels (paper, wax paper and PET) was determined. Obtained results are presented in Tab. 5.

Tab. 5. Rating of adhesive usefulness due to rating scale

Surface	Rating of adhesive usefulness		
	paper label	wax label	PET label
PET	5	5	4
Glass	9	9	9
Steel	8	9	8

The results of this research underline the crucial effect of adhesion strength to the substrate. According to the theory, increasing roughness of material surface is proportional to adhesion strength [*Ebnesajjad, 2008*]. In case of tested substrates roughness increased in presented order, PET, glass and steel – on the basis of literature data [*Absolute roughness, 2015*]. In case of PET substrate the sum of values assigned to adhesion and peel off time ranged between 4÷7, but low value of adhesion (1 according to proposed scale) disqualify adhesive as useful to combining labels with PET surface. In both glass and steel substrates the adhesion reach the maximum level according to proposed scale and this in combination with relatively short dissolution times of adhesive, allows to evaluate the used adhesive as *adhesive with very good properties to labels*.

Conclusions

The comparative method of adhesion and peel off time in water proposed and applied in this work, proved to be useful for water-soluble pressure-sensitive adhesives testing. It facilitates evaluation of usefulness of adhesive to label, taking into consideration label adhesion strength and package recycle potential.

To verify the proposed method series of experiments were conducted. Adhesion for various types of substrates and peel of time to 3 types of model labels were measured. Based on the results, the usefulness of adhesive in individual cases was determined.

Conducted experiments proved that the tested adhesive allows permanent and reversible (in appropriate conditions) adhesion of all model labels if the surface is made of glass or steel. Adhesive used in the tests is not suitable to combining labels with PET surface due to low value of adhesion (1 – according to proposed scale).

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