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A measurement system analysis with design of experiments: Investigation of the adhesion performance of a pressure sensitive adhesive with the probe tack test

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ABSTRACT

The tack of a pressure sensitive adhesive (PSA) is not an inherent material property and strongly depends on the measurement conditions. Following the concept of a measurement system analysis (MSA), influencing factors of the probe tack test were investigated by a design of experiments (DoE) approach. A response surface design with 38 runs was built to evaluate the influence of detachment speed, dwell time, contact force, adhesive film thickness and API content on tack, determined as the maximum of the stress strain curve (σ_{max}). It could be shown that all investigated factors have a significant effect on the response and that the DoE approach allowed to detect two-factorial interactions between the dwell time, the contact force, the adhesive film thickness and the API content. Surprisingly, it was found that tack increases with decreasing and not with increasing adhesive film thickness.

1. Introduction

Pressure sensitive adhesives (PSAs) are widely used in transdermal drug delivery systems (TDDS). Their adhesion performance is important for quality, efficacy and safety of transdermal patches because percutaneous drug penetration is directly linked to the contact area of the patch (Wokovich et al., 2006). The adhesive performance can be evaluated by measurement of tack, shear strength and peel adhesion. Tack is the ability to form a bond of measurable strength by simple contact with a surface (Pocius and Dillard, 2015). Tack of PSAs is not an inherent material property, as it strongly depends on the measurement conditions (Benedek, 2004).

It has been recently shown that the probe tack test can be applied as an in vitro tool with a good prediction of in vivo performance of transdermal patches (Gutschke et al., 2010). With the probe tack test the complete debonding process can be observed. The shape of the resulting stress strain curves depends on dwell time as well as on contact force, adhesive matrix thickness and detachment speed (Satas, 1999).

Tack is measured in two steps, namely the bonding step and the debonding step. During the first step, contact is made by wetting out, and viscoelastic deformation. For bond-forming good wettability with a high deformation ability is required. During the second step, deformation of the adhesive and the creation of two new surfaces occur, and therefore high mechanical strength with a strong damping behavior is required.

Thus, tack is affected by viscoelastic as well as surface properties of the adhesive. Factors influencing these properties will consequently influence tack (Venkatraman and Gale, 1998).

A modification of the bulk properties of the PSA, the dimensions of the test specimen or the test parameters of the probe tack test without knowledge about their impact on the test result can lead to mismatches between formulation development, production, quality control and end use. So far, no integrated analysis on the performance of destructive analytical tests such as the probe tack test has been implemented. Therefore, emphasis was laid on a holistic approach for testing the probe tack test equipment analogous to the method of a measurement system analysis (MSA). In particular, the focus was on possible interactions between significant influencing factors and therefore an experimental design had to be applied.

Traditionally, design of experiments (DoE) has been used to evaluate the impact of the critical process parameters (CPPs) on the critical quality attributes (CQAs) in production and development processes. However, it may also be used as a tool for the evaluation of significant factors and their influence on an analytical result. Compared to a "one-factor-at-a-time" (OFAT) method, an

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experimental design method is able to detect possible interactions with a reasonable number of experiments.

In the present study, DuroTak® 387-2287, a solvent-based crosslinked acrylic pressure sensitive adhesive (PSA) is investigated with the probe tack test by a design of experiments (DoE) approach to evaluate all significant factors and possible interactions that may influence the test result.

2. Materials and methods

2.1. Materials

The following materials were used in the study: solvent based pressure sensitive adhesive DuroTak® 387-2287 (Henkel, Bridgewater, NJ, USA), ibuprofen (BASF, Ludwigshafen, Germany), fluoropolymer coated Scotchpak® 1020 Release Liner (3 M, Neuss, Germany). All other reagents used were of analytical grade.

2.2. Methods

2.2.1. Design of experiments

To examine the significance of potential influencing factors and the linearity of the probe tack test result, five factors were chosen to be investigated: detachment speed (A), dwell time (B), contact force (C), adhesive matrix thickness (D) and API content (E).

To evaluate the main effects of these five factors, their interactions and quadratic effects a randomized response surface design with 38 runs was built (Table 1) with the Design-Expert® 8.0.6 software (Stat-Ease, Minneapolis, MN, USA). An "IV-optimal" algorithm with point exchange was used because the thickness of the adhesive matrices and the API content were adjusted to predefined levels.

The maximum of the stress strain curve of the probe tack test (σ_{max},Fig. 1d) was selected as response.

2.2.2. Preparation of adhesive matrices

For probe tack test experiments, adhesive matrices of DuroTak® 387-2287 with varying thickness and ibuprofen contents were prepared.

The non-volatile content (NVC) of the adhesive was determined as loss on drying with accurately weighed films of 2 g of adhesive at 80 °C for 24 h. The NVC was calculated as the average of five samples.

For drug-loaded films, ibuprofen was mixed with the adhesive at concentrations referring to the NVC (Table 1). The samples were shaken in an overhead shaker (in-house development) at 30 rpm and room temperature (RT) for 24 h and then stored for additional 24 h to remove air bubbles. For plain, drug free films the adhesive was used as supplied.

The wet mixes were cast on the release liner. To achieve the final thickness of dry films as shown in Table 1, a CX 4 semiautomatic lab

Table 1
Experimental design of the probe tack test with the five investigated factors detachment speed (A), dwell time (B), contact force (C), adhesive matrix thickness (D) and API content (E).

		Factor A	Factor B	Factor C	Factor D	Factor E
Standard	Run	Detachment speed (mm/s)	Dwell time (s)	Contact force (N)	Adhesive matrix thickness (μm)	API content % (w/w)
8	1	2.9	10.0	2.6	200	0
3	2	1.0	8.7	4.0	50	0
5	3	5.0	7.8	0.5	100	0
26	4	2.7	7.1	0.5	50	12
6	5	1.0	4.0	0.5	200	3
24	6	1.0	1.4	4.0	50	10
12	7	4.0	7.0	4.0	200	5
18	8	3.0	5.5	2.3	150	6
17	9	3.0	5.5	2.3	150	6
23	10	2.0	1.0	0.5	50	8
30	11	5.0	8.0	2.0	150	12
14	12	3.0	5.5	1.2	150	9
34	13	4.0	1.0	4.0	200	12
31	14	1.0	1.0	0.5	150	12
19	15	3.5	1.0	0.5	200	6
15	16	3.0	5.5	2.3	150	3
7	17	5.0	1.0	2.0	200	0
33	18	2.0	7.9	2.8	200	11
16	19	3.0	5.5	2.3	150	6
11	20	2.5	10.0	3.7	150	5
28	21	3.2	10.0	4.0	100	11
13	22	1.0	10.0	0.5	100	6
9	23	2.9	10.0	2.6	200	0
25	24	2.7	7.1	0.5	50	12
20	25	1.4	4.7	4.0	200	6
4	26	5.0	7.8	0.5	100	0
1	27	3.8	1.0	1.3	50	2
29	28	3.2	10	4.0	100	12
22	29	5.0	10	2.4	50	6
10	30	2.0	2.5	4.0	150	1
27	31	5.0	2.3	2.7	100	9
32	32	5.0	10	0.5	200	9
2	33	4.5	4.0	4.0	50	0
21	34	5.0	10	2.4	50	6
36	35	5.0	7.8	0.5	100	0
35	36	2.0	2.5	4.0	150	7
37	37	3.0	5.5	2.3	150	7
38	38	3.0	5.5	2.3	150	7