

# Controlled Delamination of Adhesives within Packaging and Distribution

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## Abstract

Controlled delamination materials introduce new exciting solutions in the packaging industry. The technology has the potential to save cost in distribution through significantly shorter handling time when transferring products from distribution packaging to store shelves. It also gives the possibility for new consumer packaging with easy opening, product presentation, effect openings, theft prevention, authenticity etc. In this document the basics of an electrically controlled adhesive is presented.

## Introduction

The mechanisms behind delamination of polymer coatings, for corrosion protection, have been an active research area for a long time. Electrochemical reactions taking place at the polymer/metal interface are generally accepted as the mechanisms for this involuntary degradation [1, 2, 3, 4].

The delamination of organic coatings taking place under natural conditions is very slow. Keller *et al.* [5] described a method for electrochemical removal of paint from steel constructions. The idea behind this method is that the delamination of the paint can be accelerated by an external power source. This method has considerable environmental and occupational advantages compared to traditional paint removal methods. This is an example of controlled delamination of a polymer film.

Controlled degradation of the mechanical properties of adhesives enables straightforward repair, replacement, recycling or short-term use of structures assembled with such materials. The degradation of the adhesive can be controlled by e.g. heat [6], solvents or electricity [7]. Electrically controlled adhesives were developed for attaching test equipment on aeroplanes [8]. In order to adapt this process to applications within packaging and distribution, it is necessary to get a

fundamental knowledge of the underlying phenomenon involved.

## Electrical Disbonding

A schematic of an electrically controlled adhesive joint is shown in figure 1. Two substrates (grey) are glued together with an ion conductive adhesive (green). An external power source is connected to form an electric circuit. A switch is used to close the circuit so that a voltage is applied over the joint, which weakens and opens.

Figure 2 shows a structure with an adhesive joint immediately after closing the switch. A current flow through the structure. In the external circuit the current is carried by negatively charged electrons whereas in the joint current it is carried by ions. At the substrate interfaces, the current is converted from electronic to ionic and vice versa. Electrochemical reactions take place at these interfaces to allow the electrical current to be carried by ions through the adhesive. These reactions cause the adhesion to become weakened so that the substrates can be separated. Depending on the nature of the adhesive and the substrates disbonding can take place at either the positively or negatively charged surface.

The polymer material that constitutes the ad-

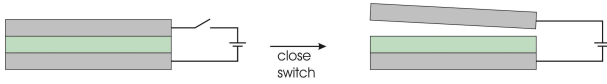


Figure 1: Schematic of an electrically controlled adhesive joint. Two conductive substrates are glued together by an adhesive. Upon closing the switch a voltage is applied over the joint, which weakens and can be opened.

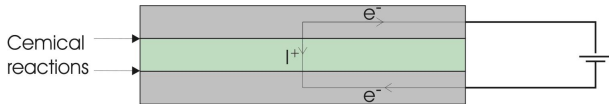


Figure 2: Delaminating structure immediately after closing of the switch. A current is carried by electrons in the outer circuit and in the substrates. Through the adhesive joint, the current is carried by ions.

hesive has a dual role. First of all it should form a strong adhesion to the substrate so that the joint can withstand sufficient shear and tensile stresses. Secondly it should act as an electrolyte allowing an ionic current to pass through it when the electrical circuit is closed. These two requirements are partially in conflict with each other. The conductivity of the electrolyte is dependent on the amount of charge carriers as well as their mobility. A high degree of cross linking is desirable in order to obtain a strong adhesive bond whereas this has a negative influence on the ionic mobility in the polymer.

The energy that is fed into the system provides the driving force for the electrode reactions as well as for passage of current through the electrolyte. Due to the relatively poor conductivity of the electrolyte most of the power is used to pass the current through the adhesive. Although the applied voltage can be relatively high, up to 50 V is mentioned in the literature [7, 8, 9], the power needed is low. This is due to the low current density, about 10 A/m<sup>2</sup>, needed to accomplish disbondment within a reasonable time. Thus, the heat production is relatively low and the temperature in the adhesive joint is not expected to change significantly during the disbondment process. Voltages as low as 3 V have also been reported to result in a controlled disbondment [9].

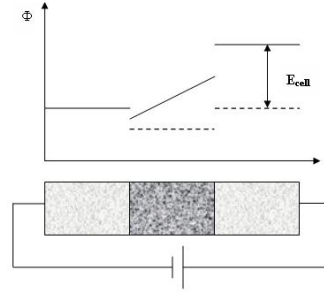


Figure 3: Schematic of the potential distribution through an adhesive joint, where both electrodes are made of the same metal, at open circuit conditions (dashed line) and under an applied voltage (solid line).

## The Electrochemical Cell

The adhesive joint composed of the two electrically conducting substrates together with the ion-conducting adhesive is an example of an electrochemical cell. An electrochemical cell consists of two electrodes of opposite polarity; an anode that donates electrons, and a cathode that consumes electrons from the external circuit. An oxidation process takes place at the surface of the anode and a reduction process at the surface of the cathode. The electrical circuit is closed by the transport of ions through the electrolyte.

In figure 3 a typical potential distribution through an adhesive joint, in which both electrodes are made of the same metal, is depicted. Under open circuit conditions, dashed lines, no current is passed through the system and hence the potential is constant through the electrolyte. The electrode potentials cancel out under open circuit conditions and hence the cell voltage,  $E_{cell}$ , is zero. When an external voltage is applied the potential jump at the electrode surfaces, known as the electrode potentials, are shifted from their equilibrium values. This change in the electrode potentials indicates that some of the applied energy is utilized in the electrode reactions. An electric field that is proportional to the current density builds up in the electrolyte. The relationship between the electric field and the current density in the electrolyte is given by the conductivity according to

$$i = -\sigma E = -\sigma \nabla \phi \approx \sigma \frac{\Delta \phi}{h}. \quad (1)$$

In the expression above  $i$  [ $\text{A}/\text{m}^2$ ] is the current density,  $\sigma$  [ $\text{S}/\text{m}$ ] is the conductivity,  $E$  [ $\text{V}/\text{m}$ ] is the electric field,  $\phi$  [ $\text{V}$ ] is the potential,  $\Delta\phi$  [ $\text{V}$ ] is the potential drop over the adhesive layer and  $h$  is the thickness  $h$  [ $\text{m}$ ] of the adhesive layer. Thus, if the conductivity is high, the ohmic potential drop through the electrolyte becomes less significant.

The conductivity of the electrolyte depends on the amount of charge carriers, their charge as well as their mobility according to,

$$\sigma = F \sum z_j c_j u_j. \quad (2)$$

The sum is taken over all mobile ionic species. In the expression above  $F$  is Faraday's constant [ $96487 \text{ C}/\text{mol}$ ],  $z_j$  is the valance,  $c_j$  [ $\text{mol}/\text{m}^3$ ] is the concentration and  $u_j$  [ $\text{m}^2/\text{sV}$ ] is the mobility of specie  $j$ . It is desirable to increase the conductivity of the electrolyte. First of all this will reduce the voltage that need to be applied in order to pass a sufficient current density through the system. Besides that the current distribution will be more uniform if the resistance through the adhesive is reduced.

In order to increase the conductivity the amount of charge carriers in the polymer mixture can be increased. The mobility of the ions in the matrix is related to the degree of cross linking and the water content of the polymer. A low degree of cross linking and high water content is desirable in order to obtain a high ionic mobility through the polymer. Generally the ionic mobility increases with temperature and decreases with the concentration of the electrolyte.

In figure 4 typical curves of the current density as a function of the applied potential is presented. Initially a relatively large current density is obtained, about  $10 \text{ A}/\text{m}^2$  at an applied voltage of  $50 \text{ V}$ . As time progresses the current density decreases. There are several plausible explanations for this behavior of the current density. It is possible that the loss of adhesion brings about an increased resistance at the metal/adhesive interface. Concentration polarizations taking place close to the electrode surfaces would also give an increased potential drop. Furthermore it is possible that reaction products can reduce the reaction kinetics at the electrode surface. During the first couple of seconds some of the current density is required for charging the double layers at the electrode surfaces.

A future improvement of the delamination technique could be to make the delaminating structure as a galvanic element. This can pos-

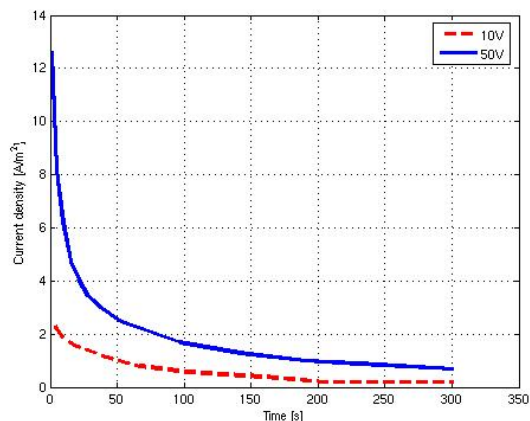


Figure 4: Current density as a function of time for different values of the applied potential.

sibly be achieved by selecting electrodes with different electrochemical potentials. The aim would be a self-powering structure which delaminates when the electrical circuit is closed. This would eliminate the need for an external power source. Another interesting idea is to use a wireless power supply, that is, by an induced voltage. The structure must then either delaminate when an AC voltage is applied over the joint or be combined with a rectifying component.

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