

## Introduction to Adhesion Science (Part 2)

### 4. Rheology of adhesion failure

The science of deformation and flow of matter is generally referred to as rheology. Rheology plays a vital role in the study of adhesion processes, including the application of viscous adhesive liquids, surface flows, penetration into narrow gaps, diffusion over interfaces, solidification, and associated internal stresses. However, this issue does not focus on them; the stress distribution involved in adhesion systems according to conditions (such as tensile or shearing, bending or twisting, and splitting or peeling forces) is clarified by material mechanics, while problems involving fractures are solved by fracture mechanics. (Nevertheless, both have limited application, constrained by the theory of elasticity.)

Rheology deals with the problem of change in forces on adhesion systems, depending on velocity; or if loading is repeated, depending on loading frequency. Since no loading is possible without velocity or frequency, and since polymer materials are typical viscoelastic bodies, this aspect cannot be ignored when discussing the strength of adhesion systems. The following discusses this concept in some detail.

### 4-1. Handling of adhesion failures by viscoelastic models

To clarify the problem, let us first consider the simplest viscoelastic models and see to what extent these models can explain adhesion failure phenomena. As shown in Figure 9, a load  $P$  is applied to the lap joint piece in the direction of the shear. The bonding area is denoted as  $S$ , the thickness of the adhesive layer as  $h$ , and the displacement as  $x$ . Here, the adherends are assumed to be rigid bodies that do not deform. The shear stress  $\sigma$  is expressed as  $\sigma = P/S$ , while shear strain  $\varepsilon$  is expressed as  $\varepsilon = x/h$ . In a constant velocity test, where the sample is pulled at a constant velocity  $v$  [ $= dx/dt$ ], the relationship  $d\varepsilon/dt = v/h$  is obtained.

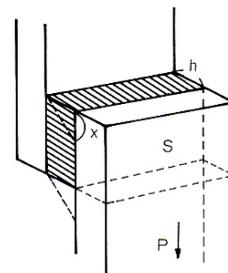


Figure 9: Shear test of bonding strength

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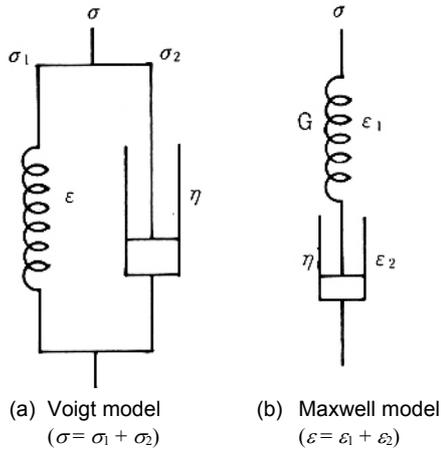


Figure 10: Simplest viscoelastic models

The deformation of the adhesive is expressed in terms of the simplest viscoelastic models, as shown in Figure 10. For the Voigt model, stress  $\sigma$  is expressed as the sum of the stresses on the spring and the dashpot:

$$\sigma = \epsilon G + \eta \frac{d\epsilon}{dt} = \epsilon G + \frac{\eta v}{h} = G \left[ \epsilon + \frac{\tau v}{h} \right] \dots \dots \dots (10)$$

Here,  $G$  is the shear modulus of the spring,  $\eta$  is the viscosity coefficient of the dashpot, and  $\tau = \eta/G$  is a value known as the relaxation time.

Similarly, for the Maxwell model, solving the differential equation that expresses the strain  $\epsilon$  as the sum of the strains of the spring and the dashpot, the stress  $\sigma$  is given as:

$$\sigma = \frac{\eta v}{h} \left\{ 1 - \exp \left[ -\frac{\epsilon_c G h}{\eta v} \right] \right\} = \frac{G \tau v}{h} \left\{ 1 - \exp \left[ -\frac{\epsilon h}{\tau v} \right] \right\} \dots \dots \dots (11)$$

To discuss adhesion failures or adhesion strength based on these rheological equations, we must first consider several problems. One is that the rheological equations essentially hold for infinitely small deformations; and it is uncertain whether the equations are valid for large deformations, particularly under the extreme conditions involved in fractures. Generally, one would conclude that the equations do not hold. However, T. L. Smith et al. have shown that in viscoelastic bodies that do not experience any special structural changes (such as crystallization) up to the fracture such as SBR, the relationship between stress and strain or the conversion rule for time and temperature hold for large deformations, even in adhesion failures, as discussed later. Thus, let us also assume that

Equations (10) and (11) can be applied here.

The next problem is the failure conditions that must be set to treat the breaking strength with equations. What are these conditions? This problem can be extremely complex, but is clear in the simple models used here. Here, assume that a fracture occurs when strain reaches  $\epsilon = \epsilon_c$ , and express the fracture stress as  $\sigma_b$ . Another problem is to distinguish between cohesion failure in the adhesive (or the adherends) and interfacial failure at the interface. This problem is solved by setting different models for each case with different failure conditions. This is discussed later. The discussion here will continue setting aside these considerations.

Assuming these premises and substituting the failure condition,  $\epsilon = \epsilon_c$ , we find that the Voigt model provides

$$\sigma_b = \epsilon_c G + \frac{\eta v}{h} = G \left[ \epsilon_c + \frac{\tau v}{h} \right] \dots \dots \dots (12)$$

and that the Maxwell model provides

$$\sigma_b = \frac{\eta v}{h} \left\{ 1 - \exp \left[ -\frac{\epsilon_c G h}{\eta v} \right] \right\} = \frac{G \tau v}{h} \left\{ 1 - \exp \left[ -\frac{\epsilon_c h}{\tau v} \right] \right\} \dots \dots \dots (13)$$

Both of these equations show that bonding strength  $\sigma_b$  increases as velocity, elasticity modulus, and viscosity coefficient (or relaxation time) increase, and as adhesive layer thickness decreases. This tendency agrees qualitatively with the behavior of real polymer adhesives. These relationships are clearly indicated by Equation (12). Figure 11 plots the relationship between  $\sigma_b$  and  $G$ ,  $\eta$ ,  $v$ , and  $h$  for Equation (13) only. The effects of temperature and molecular weight can also be accounted for through the temperature and molecular weight dependencies of  $G$  and  $\eta$  or  $\tau = \eta/G$ .

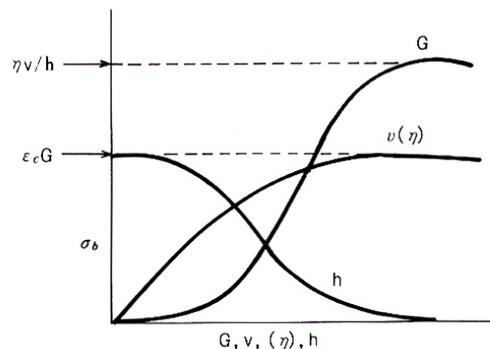


Figure 11: Effects of various factors on bonding strength (for Maxwell model)

Although the discussion thus far is based on a shear test, the results are the same for tension tests if we replace shear modulus  $G$  with Young's modulus  $E$ . However, peeling must assume another deformation mechanism, and the results for peeling are therefore completely different. For example, elasticity modulus and thickness have effects opposite to those for tension or shear.

#### 4-2. Rheology of adhesion failure mode conversion (cohesion failure $\leftrightarrow$ interfacial failure)

The discussion of the previous section assumes a single failure condition  $\varepsilon = \varepsilon_C$  without specifying cohesion failure or interfacial failure. This treatment is adequate for an adhesion system in which only one of these occurs. However in the real world, the same adhesion system will shift between cohesion and interfacial failure modes depending on various conditions, including velocity and temperature. Two examples are given below.

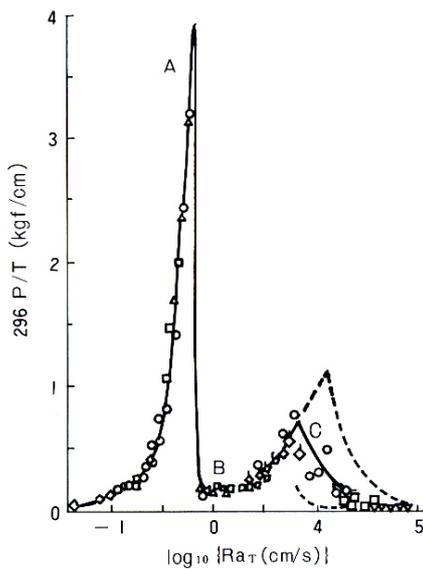


Figure 12: Master curve indicating the relationship between peel strength  $P$  and peel rate  $R$  (Reference temperature:  $23^\circ\text{C}$ ) (Gent and Petrich)

Figure 12 indicates the result obtained by Gent and Petrich, showing the master curve indicating the relationship between peel strength and peel rate [velocity] for an SBR sticky tape. The master curve is based on partial curves for the peel strength  $[P]$  - peel rate  $[R]$  relationship measured in peeling tests within a limited range of peel rates at various temperatures  $[T]$  from the flow to glass regions. The horizontal and vertical axes of the partial curves are extended by factors of  $a_T$  and  $296/T$ , respectively, to match the curve for the reference temperature,  $23^\circ\text{C}$   $[T_0 = 296\text{K}]$ . These are superposed to form a curve

covering a wide range of peel rates. This procedure is known as time [rate] - temperature conversion or superposition. Although it is a rheology issue, we will omit any further treatment in the present discussion of the temperature dependence of conversion factor  $a_T$ . [The temperature dependence of  $a_T$  in this experiment follows the WLF (Williams, Landel, and Ferry) equation.]

Figure 12 shows two peaks. However, the change from A to B is better described as a discontinuous change than as the formation of another peak. The low velocity region A corresponds to cohesion failure, region B to interfacial failure, and region C to the brittle failure of the interface. Compared to separately measured relaxation modulus changes, these correspond to the flow, rubber, and glass regions, respectively.

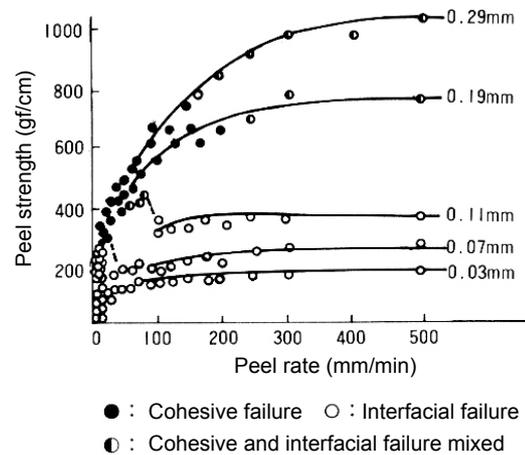


Figure 13: Relationship between peel rate and peel strength for sticky tapes of different thickness (Fukuzawa)

Fukuzawa obtained similar results from peeling experiments with varying peel rates and temperatures. Here, Figure 13 shows the relationship between peel strength and peel rate with varying thickness of the adhesive layer. The figure shows that thick samples are dominated by cohesion failure of high peel strength, while thin samples are dominated by interfacial failure of low peel strength. When thickness is moderate, failure mode changes discontinuously from cohesion failure to interfacial failure, corresponding to discontinuous change in peel strength.

The discontinuous change in peel strength and the corresponding conversion in failure modes as indicated in the above two examples can be explained only in terms of rheological characteristics. Before further discussion, it is appropriate to comment on the **WBL (weak boundary layer) theory**. Bikerman proposed that adhesion failures always occur at the weak

boundary layer near one of the interfaces, and that pure interfacial failure is impossible. According to this theory, the reason for weak bonding to crystalline polymers such as polyethylene and polypropylene is not poor surface chemical wetting, but WBL formed by low molecular weight components and additives gathered on the surface rather than absorbed. Supporting this theory, Schonhorn et al. published accounts of experiments in which reinforcing these surface layers by bridging [the CASING method] or by crystallization [the TCR method] significantly improved bonding strength. Since then, this theory appears to have dominated in the adhesive science community. The theory dismisses surface chemical approaches in treating adhesion as virtually meaningless; Schonhorn et al. have published numerous results arguing that critical surface tension  $\gamma_c$  and bonding strength are completely unrelated.

Nevertheless, the surface treatment of solids in adhesion is indisputably performed mainly to improve surface chemical properties. As discussed in 3-2, optimum surface chemical conditions can exist only by presuming interfacial failures. Although not discussed in detail previously, Figure 6 includes data originally presented by Schonhorn et al. to demonstrate the lack of systematic dependence on  $\gamma_c$ . Figure 6 replots their data with respect to  $\gamma_c^c$ . The lack of an applicable yardstick is quite likely to result in no visible relationship.

To return to the discussion, the WBL theory is also unable to account for discontinuous changes in peel strength as described in this section, since the theory assumes that the weak boundary layer is the only fracture source. (We can also account for this change by making the far-fetched assumption that two types of weak boundary layers are present.) This behavior can be understood only as the conversion in failure positions or failure modes from cohesion failure to interfacial failure, as observed by Gent and Fukuzawa. The velocity and temperature dependences indicate that this is essentially a rheological phenomenon. Thus, the following discussion uses the simplest viscoelastic model to show that adhesion failure modes can change as the result not just of velocity and temperature, but other factors, including elasticity modulus

For the sake of simplicity, let us reconsider the case of shear adhesion failure under constant velocity without deformation of the adherends.

Figure 14 shows the simplest model containing a spring (with shear modulus  $G_1$  and strain  $\epsilon_1$ ) and the adhesive layer (with shear modulus  $G_2$  viscosity coefficient  $\eta$ , and strain  $\epsilon_2$ ) described in a Voigt and horizontal model. Then, the following expression holds:

$$\sigma = \epsilon_1 G_1 = \epsilon_2 G_2 + \eta \frac{d\epsilon_2}{dt} \dots \dots \dots (14)$$

Here, the failure conditions assumed are that interfacial failure occurs if the strain in the interface spring,  $\epsilon_1$  reaches the critical value  $\epsilon_{1C}$ , and that cohesion failure occurs if the strain in the adhesive layer  $\epsilon_2$  reaches the critical value  $\epsilon_{2C}$ . The corresponding fracture stresses are expressed as  $\sigma_b^S$  and  $\sigma_b^B$ , respectively. Then,

$$\text{Interfacial failure: } \sigma_b^S = \epsilon_{1C} G_1 \dots \dots \dots (15)$$

$$\text{Cohesion failure: } \sigma_b^B = \epsilon_{2C} G_2 + \eta \left( \frac{d\epsilon_2}{dt} \right)_{\epsilon_2 = \epsilon_{2C}} \dots \dots \dots (16)$$

Which of the failures expressed in Equations (15) and (16) occurs under what conditions depends mainly on the viscosity term. When the rate of strain is large, viscous drag is also large, preventing adhesive deformation, and  $\epsilon_1 = \epsilon_{1C}$  [cohesion failure] is reached first. When the rate of strain is small,  $\epsilon_2 = \epsilon_{2C}$  [interfacial failure] is more likely to occur first.

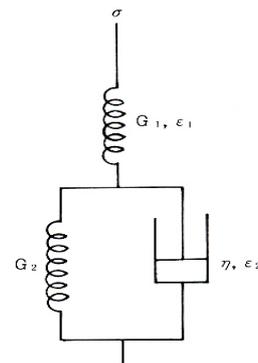


Figure 14: Simplest viscoelastic model for interfacial force and cohesive strength

Equation (16) may be rewritten as follows using the relationships  $[d\epsilon_2/dt] \epsilon_2 = \epsilon_{2C} = \epsilon_{2C}/t_{b1}$ ,  $t_b = \epsilon_b h/v$ ,  $\epsilon_b = \epsilon_1 + \epsilon_{2C}$ , and  $\sigma_b^B = \epsilon_1 G_1$  (here,  $\epsilon_b$  is total strains of failure,  $t_b$  is breaking time,  $v$  is the velocity provided by the test machine, and  $h$  is the thickness of the adhesive layer):

$$\sigma_b^B = \frac{1}{2} \left\{ \varepsilon_{2c} [G_2 - G_1] + \sqrt{\varepsilon_{2c}^2 [G_1 + G_2]^2 + 4 \varepsilon_{2c} G_1 \eta v / h} \right\} \quad (17)$$

Without velocity dependence, the strength of interfacial failure  $\sigma_b^S$  given by Equation (15) is the constant  $\varepsilon_{1c} G_1$ . However, the strength of cohesion failure  $\sigma_b^B$  given by Equation (17) increases as velocity  $v$ , elasticity modulus of adhesive layer  $G_2$ , and viscosity coefficient  $\eta$  increase, and as the thickness of adhesive layer  $h$  decreases. This tendency qualitatively explains the experimental facts observed for shearing adhesive strength. (Peeling differs.) That the increase in these factors and the decrease in  $h$  increases  $\sigma_b^B$  means that cohesion failure becomes less likely when the condition for interfacial failure  $\sigma_b^S = \varepsilon_{1c} G_1$  is preferentially more likely. The change in adhesion failure modes by temperature can also be discussed in terms of the temperature dependence of the viscosity coefficient,  $\eta$  or relaxation time,  $\tau = \eta/G_2$ .

In the above simple model, the interfacial failure value is  $\sigma_b^S = \varepsilon_{1c} G_1$ , a constant. However, due to the viscoelastic deformation of the adhesive layer toward the fracture, bonding strength can actually depend on velocity (or peel rate) and other factors [Figures 12 and 13]. The author also proposes a theory that accounts for this consideration and the failure envelope - the curve indicating that bonding strength grows with increased velocity and lower temperature and that fracture strain reaches a maximum, then declines - in cohesion failure, however, this issue does not cover it.

#### 4-3. Rheology of peeling

It is easier to peel sticky tape from a solid surface at large angles. The author first quantified this everyday experience, based on a determination of the relationship between peel angle  $\theta$  and peel strength  $P$ . Denoting the adhesion work as  $W$ , the relationship is given by the following equation for the unit width of the film.

$$W = P [1 - \cos \theta] \quad (18)$$

This equation is effectively the same as the Dupr e-Young equation,  $W_a = \gamma_L [1 + \cos \theta]$  [Equation (5)], for a liquid drop with surface tension  $\gamma_L$  in equilibrium on the surface at contact angle  $\theta$ , if the measurement method for  $\theta$  is made consistent. An equation equivalent to a surface chemical equation is obtained because Equation (18) is derived under the following assumptions.

(a) Peeling occurs under equilibrium conditions.

(The peeling proceeds extremely slowly, so that the system can be considered to maintain a quasi-equilibrium state.) (b) Work arising from deformation in the film and in the adhesive layer can be disregarded. (c) The thickness of the film can be disregarded relative to its radius of curvature. Equation (18) is consistent with experimental results. However, if any of these conditions is not satisfied - for example, in fast peeling - Equation (18) no longer holds. We will demonstrate this behavior next.

Figure 15 shows the relationship between peel strength and peel rate measured at various peel angles for a system consisting of cloth-lined polyisobutylene adhered to glass. The first notable item is that peel resistance increases by 2 to 3 orders in fast peeling compared to slow peeling. (The daily peeling rate of 0.1 cm/sec to 10 cm/sec is classified as fast here.)

If Equation (18) holds in this fast peeling region, work should be expressed as  $W$  [erg/cm<sup>2</sup>] =  $P$  [dyn/cm] for  $\theta = 90^\circ$ , for example. Thus, from the upper right value of the curve for  $90^\circ$ , we obtain  $W \approx 10^5$  erg/cm<sup>2</sup>. This value cannot be explained in terms of ordinary intermolecular forces [10<sup>2</sup> to 10<sup>3</sup> erg/cm<sup>2</sup>].

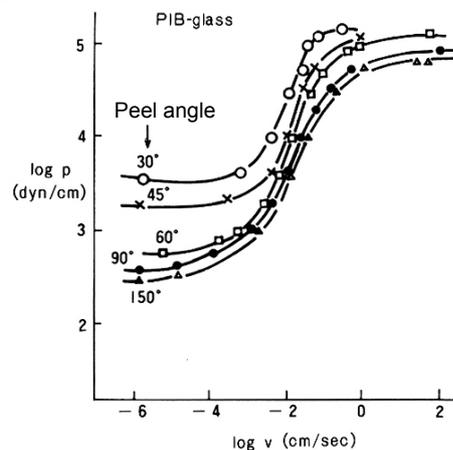


Figure 15: Relationship between peel rate and peel strength (Hata et al.)

Deryagin's **electrostatic theory** of adhesion is a theory based on this fact. In other words, he also performed  $90^\circ$  peeling with samples such as cellulose derivatives and polyvinyl chloride. Since the adhesion work obtained by the above procedure is an order of magnitude greater than intermolecular forces, he contends that the essence of adhesion is the electrostatic attractive force between the positive and negative electric double layers

generated in the interface, compiling various other experimental results, including interesting experiments concerning the dependence on atmospheric pressure of peel adhesive strength and electron emission. However, he is mistaken from the start. The point is the fact that is Equation (18) no longer holds for fast peel rates. We demonstrate this next.

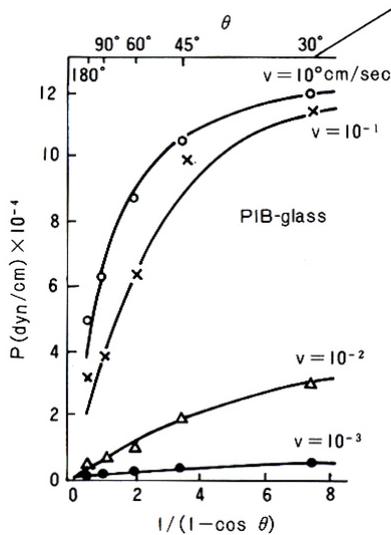


Figure 16: Relationship between peel strength P and  $1/(1 - \cos \theta)$  at each constant peel rate

Re-plotting Figure 15 as the relationship between peel strength P and  $1/[1 - \cos \theta]$  at each peel rate produces Figure 16, where  $\theta$  is the peel angle. For Equation (18) to hold, this relationship must be linear, the lines passing through the origin. However, such behavior is observed only for extremely low peel rates of  $10^{-3}$  cm/sec or less for the combination of polyisobutylene and glass (or of  $10^{-5}$  cm/sec or less in another experiment for the combination of polyvinyl acetate and glass). Here, work is  $W = 10^2$  to  $10^3$  erg/cm<sup>2</sup>, which are reasonable values for adhesion work. Deryagin made a misstep by analyzing experiments for fast peeling (as experienced in everyday life) for which Equation (18) in essence fails to hold. In this context, adequate bonding can be obtained at interfaces where no electrostatic phenomenon is observed. In sum, attributing a bonding mechanism to electrostatic forces is generally invalid. The peel rate dependence of peel strength as shown in Figure 15 is due to the rheological behavior of the film or adhesive layer. We will return to this discussion later. Here, a static treatment is used to show that

film deformation must be considered to understand this fact.

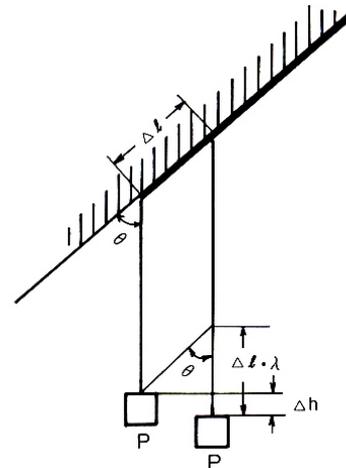


Figure 17: Peeling considering film extension

Now, consider that a unit width of the film is peeled by  $\Delta \ell$  at peel angle  $\theta$  with load P. The portion already peeled at the start is considered to have extended to an equilibrium, and load P is considered to extend the newly peeled  $\Delta \ell$  portion by factor  $\lambda$ . For the sake of simplicity, we disregard the work required for deformation. Denoting work per unit length for this extension as  $W_d$  and adhesion work per unit length due to the interfacial force as  $W_a$ , we obtain the sum of these work contributions:  $W_1 = [W_a + W_d] \Delta \ell$  equals the falling work of the load,  $W_2$ . Since  $W_d$  is given by the area of the load - strain curve as  $W_d = 1/2 \cdot P [\lambda - 1]$  within the elastic limit, we derive the following equation:

$$W_1 = \left\{ W_a + 1/2 \cdot P[\lambda - 1] \right\} \Delta \ell \dots\dots\dots(19)$$

On the other hand, the work involved in falling work of the load,  $W_2$ , is indicated in the figure.

$$W_2 = P \Delta h = P [\Delta \ell \lambda - \Delta \ell \cos \theta] \\ = P [\lambda - \cos \theta] \Delta \ell \dots\dots\dots(20)$$

Applying  $W_1 = W_2$  and rearranging the terms,

$$W_a = P \left[ \frac{\lambda + 1}{2} - \cos \theta \right] \dots\dots\dots(21)$$

When the film does not extend – in other words, when  $\lambda = 1$  – this equation reduces to Equation (18), the basic equation for peeling discussed earlier. Denoting film thickness as  $t_0$  and Young's modulus as E, the relationship  $P/t_0 = E [\lambda - 1]$  holds since the film has unit width. Recasting Equation (21) with this  $\lambda$  produces

$$W_a = P [1 - \cos \theta] + \frac{P^2}{2t_o E} \dots\dots\dots(22)$$

Here again, Equation (22) reduces to Equation (18) in the absence of deformation ( $E \rightarrow \infty$ ). Equation (22) is a quadratic equation with respect to P. Equation (22) is used to calculate the theoretical curves shown with solid curves in Figure (16), treating  $W_a$  and E as experimental parameters. The theoretical curves are in good agreement with the experimental values. Deviations from the basic equation for peeling or high bonding strength is due to the work involved in film deformation. There is no need to introduce interfacial electrostatic effects a la Deryagin.

The above treatment based on the theory of elasticity does not account for velocity dependence. Additionally, film extension after the film is peeled from the surface is regarded as deformation, which should be disregarded, since the actual films, including sticky tape, are supported by a strong lining. Instead, we must consider the viscoelastic deformation of the adhesive layer at the peel edge. [Figure 18]

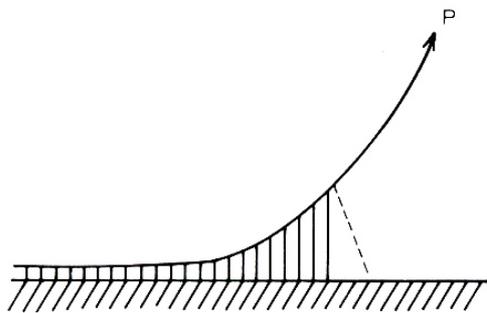


Figure 18: Deformation of the adhesive layer at the peel edge

Based on such models, the author first quantified the velocity dependence of peel strength theoretically as a rheological phenomenon, as shown in Figure 15. On this basis, researchers, primarily Japanese, have elaborated the rheology of peeling. A discussion of this topic is omitted here, due to its complexity.

As discussed in this and the two previous sections, **the rheology theory** of adhesion is an approach that treats changes in failure modes as well as velocity (peel rate) and temperature dependence of bonding strength as rheological phenomena.

## 5. Postscript

As stated at the outset, adhesion encompasses various processes, and the related science and technologies are based on the integration of numerous fundamental branches of science. The study of adhesion is more accurately characterized by the term multidiscipline than inter-discipline. Although knowing various subtleties of the phenomenon may remain elusive to scientists and engineers, I wish to underscore my belief that proper understanding will result only from such a broad-ranging approach to the problem.

Although the preceding article omits specific references, I wish interested readers to refer the following sources.

<Reference Cited>

- 1) Theory of adhesion: Handbook of adhesion (First edition), 27 pages [1971, the Nikkan Kogyo Shimbun, Ltd]
- 2) Adhesion of surface chemistry: Handbook of adhesion (Revised edition), 24 pages [1980]
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————— Scheduled for the next issue: —————

### Boundary Lubrication and Lubricants

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Tokyo Institute of Technology

1. Introduction
2. Boundary lubrication mode
3. Wear in boundary lubrication
4. Formation of lubricating films
5. Solid lubricants
6. Friction modification

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## PANDO 29B



PANDO 29B was developed specifically to clean electronic equipment, precision equipment, and plastic components, with a special emphasis on safety. (Ordinance on Prevention of Organic Solvent Poisoning of Japan does not apply to PANDO 29B.) PANDO 29B is a cleaner for electronic equipment that is nonflammable and does not corrode plastic, rubber, metal, or paint. PANDO 29B contains no nonvolatile component and leaves no contaminants on surfaces to which it is applied.

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PANDO 65A contains super fine particles of fluorocarbon resin that remove dirt from the surface of aluminum, stainless steel, and plastics, while simultaneously forming a powerful protective coating. PANDO 65A is the ideal surface activity protection agent for safeguarding against dirt and corrosion for five times longer than conventional products.

The Pando series products were released in July 1982 for distribution through licensed agents. Beginning this January, eight new products join the Pando line. We plan to continue commercializing products for specific needs across a wide range of fields, including (1) adhesives, (2) sealants, (3) lubricants, (4) rust inhibitors, (5) cleaners, (6) coating agents, and (7) repairing agents, with the goal of providing optimal performance and quality to meet the demands of the market. Please contact our sales technicians for inquiries about Pando series products.

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PANDO 39B is a chemical scraper for removing gaskets and adhesives bonded to flange surfaces and joints. Simply brush on to surfaces to easily remove gaskets. PANDO 39B reduces workload and ensures thorough maintenance.

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PANDO 39C effectively releases molds for any molding materials. Silicone based, PANDO 39C offers superior heat resistance without producing carbonization impurities. It improves workability without smearing of the mold or products. The stability of silicone means PANDO 39C will not corrode or contaminate molds or products. PANDO 39C is effective in releasing products of virtually unlimited complexity.

### Metal mold release agent (paintable type)

## PANDO 39D

Molded products are often covered with mold release agents, which inhibit painting or labeling. PANDO 39D is a special paintable mold release agent that does not require degreasing to remove the agents, enabling direct painting and labeling.



## Related overseas information

Six years have passed since Three Bond opened a representative office in Singapore, a South Asian metropolis, at the beginning of 1977. We have established service systems in the region (Thailand, Malaysia, Philippines, Australia, New Zealand, and Indonesia), and three staff members assigned to the office are working hard to expand training and sales.

For the most part, the factories in the region are small home industry production plants, except for those owned by foreign-affiliated companies. In addition to improvements in quality and workability, numerous technical problems await solutions.

As a specialized manufacturer of adhesion and sealing technology, Three Bond hopes that its products will prove truly useful to the people of South East Asia and provide them with the means to further their hopes and dreams.

Recently, Three Bond helped resolve a number of problems related to major construction projects in East Malaysia, including the repair of oil tanks (anticorrosive linings) and sealants for underground railway construction (shield tunneling construction). Such successes add to our list of achievements.

We are doing our utmost to serve as a useful representative office for our customers in this region that straddles the equator, and wish to express our sincere appreciation for the continuing support of our customers.



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