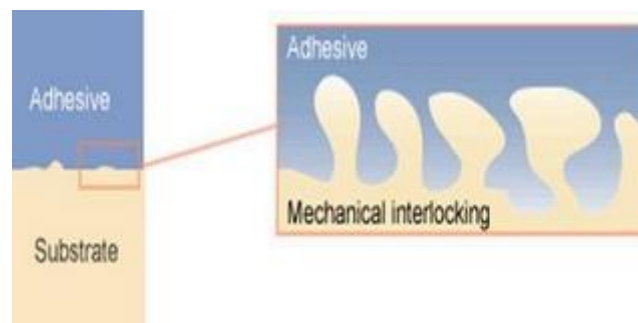


Theories of Adhesion

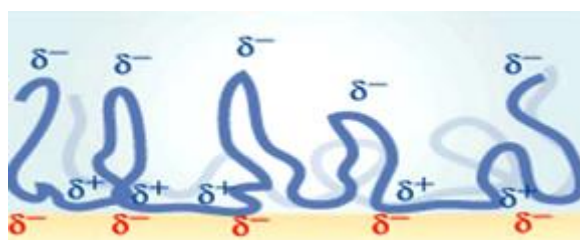
Mechanical Theory

According to mechanical theory, adhesion occurs by the penetration of adhesives into pores, cavities, and other surface irregularities of the surface of the substrate or adherend. The adhesive displaces the trapped air at the interface. Therefore, it is concluded that an adhesive penetrating into the surface roughness of two adherends can bond the two. A positive contribution to the adhesive bond strength results from the “mechanical interlocking” of the adhesive and the adherends (Ebnesajjad, n.d.).



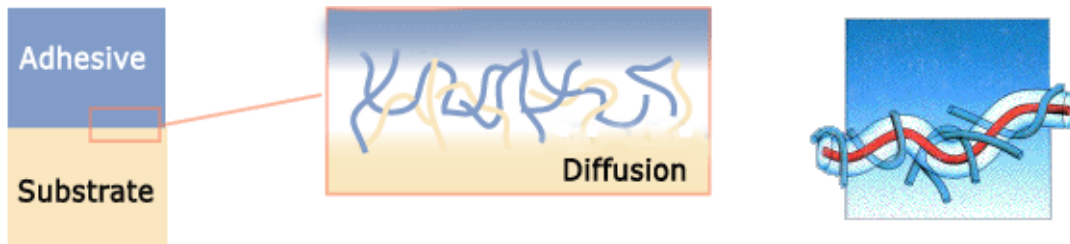
Electrostatic (Electronic) Theory

This theory proposes that adhesion takes place due to electrostatic effects between adhesive and adherend. An electron transfer theoretically takes place between the adhesive and the adherend as a result of unlike electronic band structures. Electrostatic forces in the form of an electrical double layer are thus formed at the adhesive-adherend interface. These forces account for the resistance to separating. This theory gains support from the fact that electrical discharges have been observed when an adhesive is peeled from a substrate.



Diffusion Theory

This theory suggests that adhesion is developed through the interdiffusion of molecules in and between the adhesive and adherend. The diffusion theory is primarily applicable when both the adhesive and adherend are polymers with relatively long-chain molecules capable of movement. The nature of materials and bonding conditions will influence if, and to what extent, diffusion takes place. The diffuse interfacial (interphase) layer typically has a thickness in the range of 10 Å–1,000 Å. Solvent cementing or heat welding of thermoplastics is considered to be a result of diffusion of molecules.



Cohesive energy density [CED, Eq. (1)] can be used to interpret diffusion bonding, as defined by Eq. (2). Bond strength is maximized when solubility parameters between adhesive and adherend are matched.

$$\text{Eq. (1)} \quad \text{CED} = \frac{E_{coh}}{V}$$

$$\text{Eq. (2)} \quad \delta = \sqrt{\frac{E_{coh}}{V}}$$

E_{coh} is the amount of energy required to separate molecules to an infinite distance,

V is the molar volume, and

δ is the solubility parameter.

A relevant example is adhesion of polyethylene and polypropylene to a butyl rubber. The adhesive bond is weak when two polymers are bonded at temperatures below the melting point of polyolefin. Bond strength grows sharply when the adhesion process takes place above the melting temperature of polyethylene (135°C) and polypropylene (175°C). Figure (1) illustrates the bond strength (peel strength) as a function of bonding temperature. An inference can be made that at elevated temperatures, interdiffusion of polyolefins and butyl rubber increases, leading to higher bond strength.

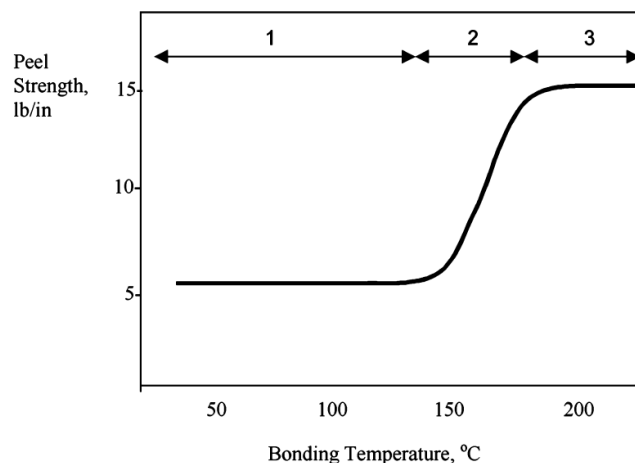


Figure 1 Peel strength of polypropylene and butyl rubber vs a bonding temperature. 1. Adhesive failure; 2. adhesive/cohesive failure; and 3. cohesive failure.

Wetting Theory

This theory proposes that adhesion results from molecular contact of two materials and the surface forces that develop between them. The first step in bond formation is to develop interfacial forces between the adhesive and the substrates. The process of establishing continuous contact between the adhesive and the adherend is called wetting. For an adhesive to wet a solid surface, the adhesive should have a lower surface tension than the critical surface tension of the solid, which is the reason for the surface treatment of plastics.

Figure (2) illustrates complete and incomplete wetting of an adhesive spreading over a surface. Good wetting results when the adhesive flows into the valleys and crevices on the substrate surface. Poor wetting occurs when the adhesive bridges over the valley and results in a reduction of the actual contact area between the adhesive and adherend, and thus a lower overall joint strength. Incomplete wetting generates interfacial defects, thereby reducing the adhesive bond strength. Complete wetting achieves the highest bond strength.

Most organic adhesives readily wet metal adherends. On the other hand, many solid organic substrates have surface tensions lower than those of common adhesives. The criteria for good wetting requires the adhesives to have a lower surface tension than the substrate. This explains, in part, why organic adhesives such as epoxies have excellent adhesion to metals, but offer weak adhesion on untreated polymeric substrates such as polyethylene, polypropylene, and fluoroplastics. Surface energy of plastic substrates is increased by various treatment techniques to allow wetting.

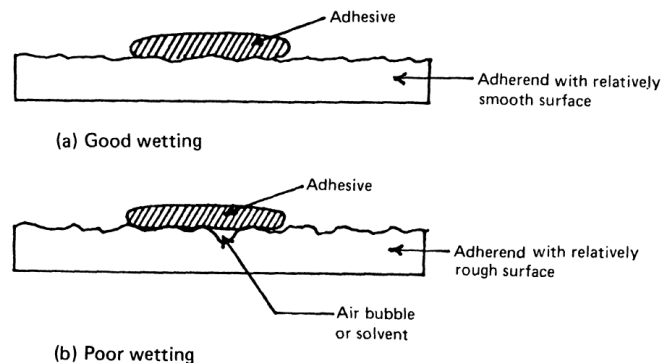


Figure 2 Examples of good and poor wetting by an adhesive spreading across a surface. Modified after Schneberger.

Chemical Bonding

This mechanism attributes the formation of an adhesion bond to surface chemical forces. Hydrogen, covalent, and ionic bonds formed between the adhesive and adherends are stronger than the dispersion's attractive forces. Table 1 shows a list of these forces and their magnitudes. In general, there are four types of interactions that take place during chemical bonding: covalent bonds, hydrogen bonds, Lifshitz-van der Waals forces, and acidbase interactions. The exact nature of the interactions for a given adhesive bond depends on the chemical composition of the interface.

Type	Example	E (kJ/mol)
Covalent	C–C	350
Ion-Ion	Na ⁺ ...Cl ⁻	450
Ion-Dipole	Na ⁺ ...CF ₃ H	33
Dipole-Dipole	CF ₃ H...CF ₃ H	2
London Dispersion	CF ₄ ...CF ₄	2
Hydrogen Bonding	H ₂ O...H ₂ O	24

Acid-Base Theory of Adhesion

A special type of interaction, the acid-base theory, is a fairly recent discovery. It is based on the chemical concept of Lewis acid and base. The Lewis definitions are: “An acid is a substance which can accept an electron pair from a base; a base is a substance which can donate an electron pair.

According to acid/base theory, adhesion results from the polar attraction of Lewis acids and bases (i.e., electron-poor and electron-rich elements) at the interface.

Weak Boundary Layer Theory

This theory, first described by Bikerman, states that bond failure at the interface is caused by either a cohesive break or a weak boundary layer. Weak boundary layers can originate from the adhesive, the adherend, the environment, or a combination of any of the three. Weak boundary layers can occur in the adhesive or adherend if an impurity concentrates near the bonding surface and forms a weak attachment to the substrate. When failure takes place, it is the weak boundary layer that fails, although failure appears to take place at the adhesive-adherend interface.

Definition of Failure Modes

A hypothetical adhesion bond is illustrated in Fig. 3. Assume that the bond is tested in the tensile mode in which the two adherends are pulled apart in the direction perpendicular to the bond. There are different possibilities for the occurrence of failure. The surfaces involved in bond failure are called the *locus* of failure fig.4.

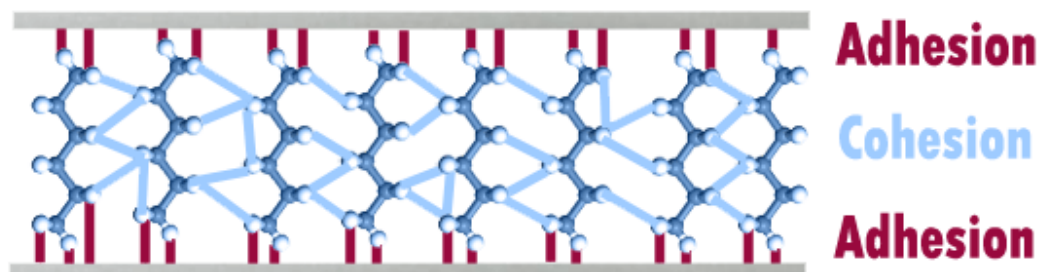


Figure 3

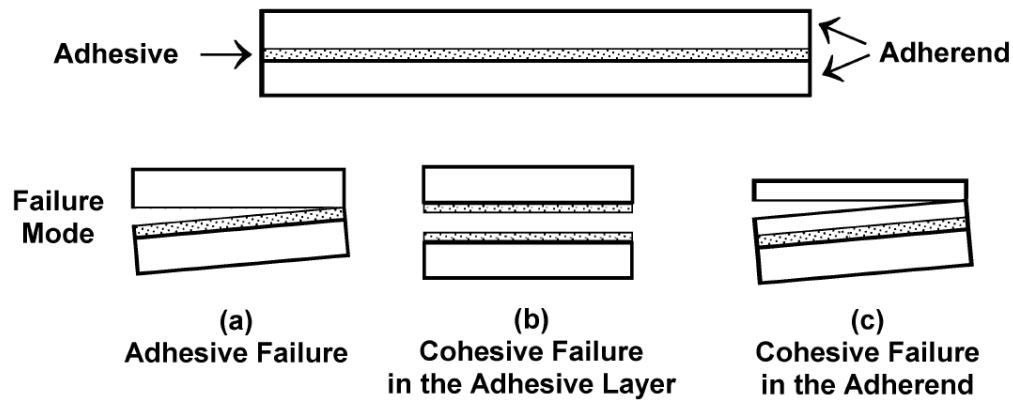


Figure 4 Schematics of adhesive bond failure modes.

If the bond failure occurs between the adhesive layer and one of the adherends, it is called *adhesive failure* [Fig. 3 (a)]. A failure in which the separation occurs in a manner that both adherend surfaces remain covered with the adhesive is called *cohesive failure* in the adhesive layer [Fig. 3 (b) and (c)]. Sometimes the adhesive bond is so strong that the failure occurs in one of the adherends away from the bond. This is called a cohesive failure in the adherend. Bond failures often involve more than one failure mode and are ascribed as a percentage to cohesive or adhesive failure. This percentage is calculated based on the fraction of the area of the contact surface that has failed cohesively or adhesively.

References

Ebnesajjad, C. F. (n.d.). **Surface Treatment of Materials for Adhesion Bonding** assisted by, Copyright © 2006 by William Andrew, Inc.