Advanced Adhesion and Bonding

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Introduction

The following article provides an overview of JPL Publications D-17926: Advanced Adhesion & Bonding.

Executive Summary

Structural integrity of an adhesive bond that holds together two dissimilar materials is determined by a discouragingly large set of factors. The primary objective of this work is to provide an engineer practicing in the field of aerospace/aircraft industry with a concise overview of the basic principles, design recommendations and other characteristic parameters needed for a complete description of the quality of the adhesive bond. This review incorporates essential elements of Chemistry, Physics, Mechanics, Mathematics and technological requirements that are pertinent to the subject matter.

One may then describe the collection of four chapters that follow as a compendium that summarizes our state-of-the-art know-how relating to the chemical, thermal, mechanical properties as well as the strength and range of applications (and their limitations) of the commercially available adhesives. Also certain design procedures are discussed and shown how they can be used to plan for manufacturing of a new product with pre-determined properties.

The report consists of four chapters, but the substance of the entire text may be readily divided into two major groups: fundamental and applied. Chapter 1 belongs in its entirety to the first group. This chapter summarizes our present knowledge and provides an information of fundamental nature about the intermolecular forces and about the reversible (elastic) and irreversible (viscous and plastic flow type) deformation processes, which precede the final act of bond fracture.

To understand the nature of state of stress induced in the immediate vicinity of fracture front and that existing within the bulk of deformable bodies participating in transmission of loads through the bonded contact area, it is necessary to consider five sub-elements, all of which take part in the global deformation and fracture processes. These sub-components are:

1. Adherend No. 1,
2. Interface between the adhesive and adherend No. 1,
3. Adhesive layer,
4. Interface between the adhesive and adherend No. 2,
5. Adherend No. 2.

If fracture propagates along one of the interfaces, it is referred to as the **adhesive fracture** characterized by the specific energy of adhesion, G_a. If, on the other hand, the chemical bond within the interfaces is stronger than the molecular attraction of either one of the adherends, then the cohesive fracture propagates through one of the joined elastic substrates, and it is characterized by the **cohesive fracture energy**, G_c. Since almost every adhesive is a composite material, and at the same time we have to deal with interfaces and adherends, which frequently possess dissimilar elastic moduli, it becomes apparent that the complexity of required mathematical modeling requires a profound knowledge of the pertinent principles of Materials Science, Chemistry and Physics. Chapter 1 explains some of the first principles involved in the Mechanics of bond performance (such as the concept of energy balance at the onset of fracture, for instance), while certain rules of Thermodynamics of the bonding process are discussed in Chapter 4. Both chapters provide a useful insight into the complex phenomena of the bonding process. A reader who wishes to gain a somewhat deeper understanding of "how" and "why" things work as they do, will find reading of these two chapters useful.

Those interested in the technological aspects of adhesion will find a wealth of information in Chapter 2 and Chapter 3. Let us briefly mention the important topics belonging to this category such as adhesives used in Micro-Electro-Mechanical (MEMS) devices, package sealing and encapsulation, hermetic packaging, sealing by soldering, brazing, welding, laser welding and other methods used in aerospace and aircraft industries. Quality assurance and product evaluation techniques are discussed in the context of their appropriate applications. Special attention is paid to the non-destructive methods of evaluations, including X-ray radiography, acoustic microscopy and particle impact noise detection. Modes of failure are discussed along with a brief description of fatigue failure and time-dependent fracture caused by chemically aggressive environments, often referred to as "stress corrosion", a process which accounts for the synergistic effects of stress and chemical weakening of the intermolecular bond.

Finally, the response of adhesives subjected to extreme temperatures, either low or high, is reviewed in the context of space applications.

Chapter 3 is devoted to the thin film technologies, including growth and deposition of the film particles by thermal evaporation, resistive heating, electron-beam method, RF induction technique and sputtering. An important method of deposition of poly-silicon structural material is also discussed, and a mention of stiction and supercritical cleaning is made. These latter techniques are essential for the space applications promoted by NASA.

Chapter 4 reviews the approaches used in the selection of specific types of adhesives for a designated application. First, it emphasizes the advantages of adhesive bonding over other technologies intended for joining two materials. Then, it describes the various kinds of adhesives available for the job. Matching an adhesive to an adherend is discussed in the context of their chemical compatibility. Two characteristic entities are defined, critical surface energy and solubility parameter; and then shown how they can be used to define the proper selection of an adhesive for a given adherend, or vice versa. Guidelines are provided for designing a compatible pair of adhesive/adherend. A number of criteria to determine quantitatively the quality of the bond are described. In this class you will find such determining parameters as threshold strength, pressure sensitivity, rate and temperature effects, autohesion, interdiffusion and influence of molecular weight on the bond quality.

B A list of relatively simple testing procedures intended to determine specific energy of adhesion is carefully composed. Each technique is illustrated by an example, and the essential equations that relate the applied load to the characteristic energy of adhesion, G_a, are provided. This list incorporates the test configurations such as tensile detachment, contoured double-cantilever beam designed for steady-state fracture investigation, peel resistance test, pull-off test and the so-called "blister" (or bubble) test. Each of these techniques offers its unique advantages; some are suitable for soft adhesives with high degree of compliance, and others serve well to examine the mechanical response of the structural adhesives.

Interestingly, the Griffith concept of the energy criterion for fracture is used throughout most of the sections in Chapter 4, thus providing a conceptual continuity and demonstrating the usefulness of the theoretical foundation laid down in some detail in the introductory chapter, Chapter 1. Some references to Nonlinear Fracture Mechanics are also made, but these fall beyond the scope of this compendium intended for engineers rather than advanced research personnel.

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