Adhesion and Adhesives

SCIENCE AND TECHNOLOGY

A.J. Kinloch

CHAPMAN AND HALL

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To my parents, my wife Gillian
and my children Ian, Elizabeth and David

Preface

Over the last decade, or so, the growth in the use of adhesives, especially in ever more technically demanding applications, has been rapid and many major developments in the technology of adhesives have been reported. This growth has also led to attention being focused on somewhat more basic studies of the science of adhesion and adhesives, and in recent years our level of fundamental knowledge concerning the formation and mechanical performance of adhesive joints has increased dramatically. Such studies have, of course, been aided greatly by the development of the tools at the disposal of the investigators. For example, specific surface analytical techniques, such as X-ray photoelectron and secondary-ion mass spectroscopy, and the increasingly sophisticated methods of stress analysis and fracture mechanics have been put to good use in furthering our understanding of the science of adhesion and adhesives. The present book attempts to review the multidisciplined subject of adhesion and adhesives, considering both the science and technology involved in the formation and mechanical performance of adhesive joints.

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Contents

CHAPTER ONE

Introduction

An *adhesive* may be defined as a material which when applied to surfaces of materials can join them together and resist separation. Adhesive is the general term and includes cement, glue, paste, etc. and these terms are all used essentially interchangeably. Various descriptive adjectives are often applied to indicate certain characteristics. For example, to indicate the physical form of the adhesive, e.g. *liquid adhesive*, *liquid two-part adhesive*, *film adhesive*; its chemical form, e.g. *epoxy adhesive*, *cyanoacrylate adhesive*, *polychloroprene adhesive*; to indicate the type of materials bonded, e.g. *metal-to-metal adhesive*, *paper adhesive*, *wood adhesive*; or to show the conditions of use, e.g. *solvent-based adhesive*, *cold-hardening*, or *-curing*, *adhesive*, *hot-melt adhesive*.

The term *adhesion* is used when referring to the attraction between the substances. As will become evident later, the level of adhesion forces which are operating across an interface cannot usually be measured by mechanical tests. For example, the measured energy for interfacial fracture is generally orders of magnitude higher than that arising solely from the *intrinsic adhesion* forces, such as molecular van der Waals' forces or covalent bonds, which may be operating across the interface.

The materials being joined are commonly referred to as the *substrates* or *adherends*. The latter term is sometimes employed when the materials are part of a joint, but in the present text only the term substrate will be used. In the following chapters the importance of considering the adhesive joint from the viewpoint of being an '*adhesive system*' will be emphasized. The term adhesive system is employed to indicate that, for many aspects of the performance of adhesive joints, other factors besides the physical and chemical properties of the selected adhesive may be of importance. For example, parameters such as the type of alloy selected for the substrate and the form of any surface pretreatment or primer chosen for the substrates may be extremely important. Indeed, in many instances, such parameters may be the main factors in determining whether the adhesive joint will perform adequately, especially with respect to attaining the desired service-life from the bonded structure.

Also, of course, the exact details of the *joint design*, e.g. the geometric features of the joint and the way in which the applied loads are transmitted from one substrate to the other, will greatly influence the observed mechanical behaviour of the bonded joint.

As a means of joining materials adhesives have been used by mankind for many centuries. However, it is only in the last 50 years, or so, that the science and technology of adhesion and adhesives has really progressed significantly and the major advances that have been made may be traced from the middle of the 1940s. The main reason for this is that the adhesives employed in nearly all the technically demanding applications are based upon synthetic polymers. As discussed later, such materials possess the balance of properties that enables them to adhere readily to other materials and to have an adequate strength so that they are capable of transmitting the applied loads or forces from one substrate to the other. The use of adhesives in technically demanding applications has provided the spur for the research and development of new, improved materials and identified the need for, and supported, studies on the more fundamental aspects of the underlying science. The wide range of synthetic polymers, and ancillary products such as hardeners, stabilizers, toughening additives, etc., which have become available over the last few decades, has enabled the adhesives technologist to develop specific adhesive formulations to meet the manufacturing and performance requirements of very diverse applications for both industrial and domestic applications.

Notwithstanding the above comments, solely meeting the manufacturing and performance requirements of a given industry is generally an insufficient reason for any industry to adopt a new technology, with all the teething problems that such an adoption usually implies. However, a driving force for the development and continual growth of the adhesives market is the many advantages that they offer compared with other, more traditional, techniques for fastening materials, such as brazing, welding, riveting, bolting, etc.

Advantages that adhesives can offer include:

(a) The ability to join dissimilar materials; e.g. the joining of metals, plastics, rubbers, fibre-composites, wood, paper products, etc.
(b) The ability to join thin sheet-material efficiently. This is a major use of adhesives for joining both metallic and non-metallic materials. Compared to metallic substrates, adhesives, being based largely upon organic polymers, do not possess anywhere near the level of tensile fracture strengths exhibited by most metals but when used to join relatively thin sheets of metal their strengths are usually more than adequate.
(c) An improved stress distribution in the joint which imparts, for example, a very good dynamic-fatigue resistance to the bonded component.
(d) The fact that they frequently represent the most convenient and cost-effective technique. Indeed, the bonding operation can often be auto-

mated. This obviously removes the necessity for any human operator to mix together the various components of the adhesive, if required, apply the adhesive to the correct location and repeat the procedure correctly many hundreds of times a day. Also, as demonstrated by the vehicle manufacturing industries, adhesives may be readily adapted to robotic assembly techniques.

(e) An increase in design flexibility which enables novel design concepts to be implemented and allows a wider choice of materials to be available to the designer. A good example of these advantages is honeycomb structures where a honeycomb core is faced with two adhesively bonded sheets of material to produce a structure with a very good stiffness-to-weight ratio. The materials may be metallic, non-metallic or combinations of both.
(f) An improvement in the appearance of the fastened structure; for example, if adhesives are used instead of spot-welding then the smooth, blemish-free, appearance of the bonded structure is more appealing to the consumer.
(g) An improvement in corrosion resistance. The above comparison to the spot-welded component serves as a good example where the use of a well-selected adhesive system will inherently result in far less corrosion.

However, as with any technology, there are some disadvantages:

(a) To attain long service-life from adhesive joints in very severe, hostile environments may often require the use of a surface pretreatment process for the substrates being joined.
(b) Compared to other fastening techniques such as welding, riveting, etc. the upper service-temperatures that adhesives can withstand are limited.
(c) As remarked above, the strength and toughness of adhesives in tension or shear is relatively low compared to many metals. Hence, whilst adhesives are very effective at joining thin sheets of metal, they are not typically used for joining thick metallic components, unless the bonded area is large or the adhesive is kept in compression.
(d) Non-destructive test methods for adhesive joints are relatively limited compared to those used with other fastening methods.

To illustrate these various points and show some of the very wide uses of adhesives the reader is referred to Figs 1.1 to 1.20. From these applications it is obvious that adhesives now play a most important role in the fastening of materials. They clearly demonstrate that, whilst uses of adhesives in the home, particularly by the do-it-yourself enthusiast, represent a valuable service to mankind and a vital market for the adhesives supplier, modern adhesives are not confined to such domestic applications. Indeed, adhesives are currently employed in industrial applications of all kinds and the applications illustrated reveal that adhesives are used in some of the most critical areas in engineering structures and in some of the most demanding environments, and that they have a good history of meeting the performance and service-life requirements.

If the various stages in the formation of adhesive joints are considered then several important requirements have to be met during the bonding operation. The first stage in the formation of an adhesive joint is the attainment of interfacial contact between the adhesive and substrates and this aspect is considered in Chapter 2. Having obtained intimate interfacial contact then some form of intrinsic adhesion forces needs to be established between the adhesive and substrates, and such intrinsic adhesion forces will hold the materials together throughout the service-life of the joint. Strictly, the exception to this statement is when solely mechanical interlocking occurs between the adhesive and substrates, since then neither the attainment of intimate interfacial contact nor the establishment of intrinsic adhesion forces need to be proposed. The types of intrinsic adhesion forces that may operate across an interface, which in the present text is taken to include mechanical interlocking at the interface for the sake of conciseness and clarity, are reviewed in Chapter 3.

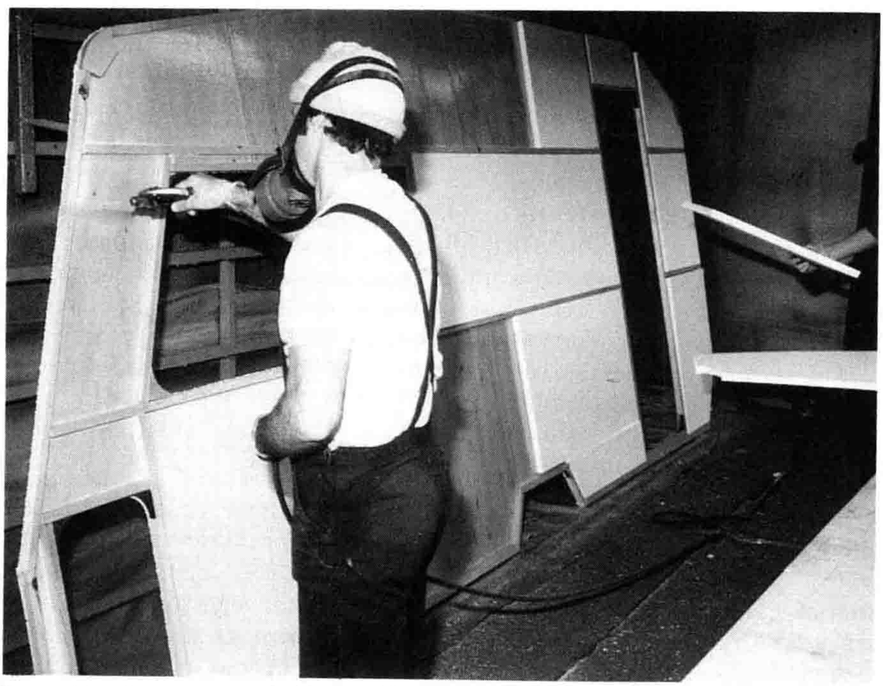

Figure 1.1 A caravan sandwich panel being sprayed with a moisture-hardening rubbery polyurethane adhesive, in a solvent, prior to bonding on the inner skin. The absence of mechanical fasteners greatly increases the production rate and results in a more pleasing appearance.

Figure 1.2 Ice cream and fruit dishes are assembled using an acrylic adhesive which is hardened by the application of an ultraviolet light source.

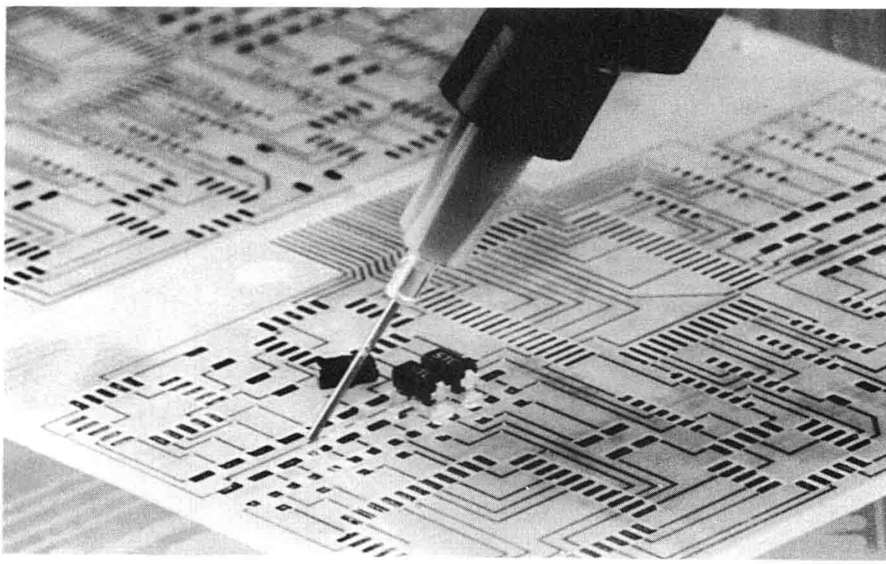

Figure 1.3 Electronic microchips may be mounted onto the printed circuit board using a very fast, room-temperature (via ultraviolet light) or hot-temperature hardening acrylic adhesive. Electronic applications invariably involve a large number of interfaces between different materials and the use of adhesives in the electronics industry is one of the most exciting growth areas for adhesive bonding.

Figure 1.4 Fast, room-temperature hardening, single-part cyanoacrylate adhesives are widely used for bonding metallic, plastic, rubber and wooden substrates, such as in attaching the rubber recoil pad to this hardwood gun stock.

Figure 1.5 Cyanoacrylate adhesives are also used to assemble loudspeakers.

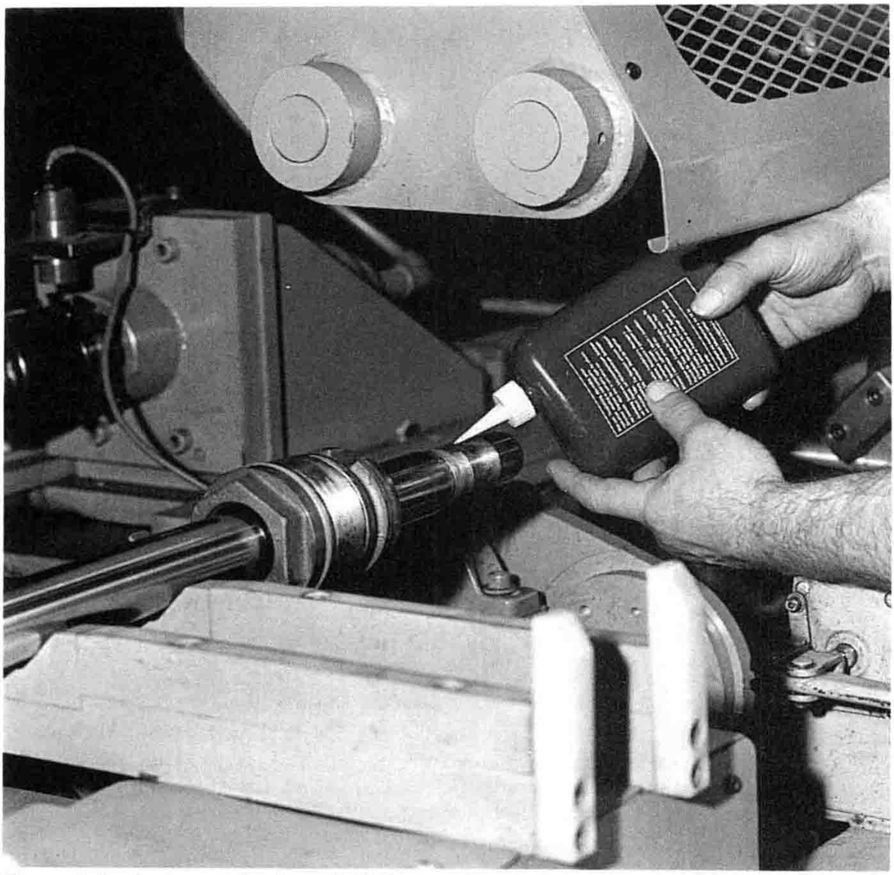

Figure 1.6 In the production of this heavy-duty engine, prior to fitting the piston head to the threaded end of the piston rod, the thread is coated with an anaerobic acrylic adhesive to ensure that the piston is held firmly in position. Such adhesives harden in the absence of oxygen.

The discussions in Chapters 2 and 3 emphasize that some form of surface pretreatment is often required in order for the bonded component to meet the necessary levels of service performance and life. Therefore, Chapter 4 reviews this very important aspect of adhesives technology in some detail. To achieve the earlier requirement of attaining intimate interfacial contact the adhesive had to be in a 'liquid' form at some stage during the bonding operation. However, the adhesive almost invariably now has to harden in order to be able to withstand the stresses and strains that may be applied to the joint. This aspect is considered in Chapter 5. However, unlike the other chapters, this chapter is not intended as an in-depth review, principally because such a review would