# Engineer's Handbook of ADHESIVES

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Edited
by
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# Foreword

The thanks of everybody concerned in this publication are due to the two adhesives manufacturing companies, CIBA-Geigy (UK) Ltd Plastics Division and Dunlop Chemical Products Division, whose advice and co-operation have made it possible in its present form.

Of the six authors whose knowledge and experience inform the body of the work, Mr C A A Rayner was Research Manager of CIBA ARL Ltd–now CIBA-Geigy (UK) Ltd Plastics Division –until his retirement in 1969; Dr G Fairbairn was until 1971 Superintendent of the Structures Laboratory, CIBA-Geigy (UK) Ltd Bonded Structures Division; Mr W F Bennett is Technical Service Manager, Mr E B McMullon Marketing Manager and Mr D T S Ilett Technical Author in the Bonded Structures Division of CIBA-Geigy (UK) Ltd; while Mr C D Mitchell is Market Research Manager in the Dunlop Chemical Products Division. It should be explained, however, that though both firms have endorsed the work in principle and encouraged members of their staff to take part in its production, they are not responsible for the details of text and presentation.

Thanks are also due to the two companies for permission to reproduce the many photographs and diagrams with which the book is illustrated. Of these, special attention should be drawn to Dr Fairbairn's magnificent electron micrographs of metal surfaces in Figs 4.3 to 4.8 which are here published for the first time.

# Contents

# Chapter 1

# Introduction

**By the Editor**

This book has been written primarily for mechanical engineers, for whom adhesive bonding is a relatively new technique, but capable of offering many advantages over welding, riveting, bolting and other traditional methods of attachment. Its aim is to give practical information about the materials available and what they can be expected to do, and practical advice about how they can be most effectively used. It does not attempt to deal in detail with the use of adhesives in such industries as packaging, bookbinding, stationery, footwear manufacture, building and civil engineering.

Moreover the large and important range of adhesives which has been developed for gluing wood, and the techniques employed for the manufacture of plywood, particle board, and laminated wood beams have been touched on only in passing. Interest has been concentrated instead on metal bonding adhesives and the techniques for their use, which have been largely pioneered by the aircraft and automobile industries and are now spreading to all branches of mechanical engineering.

*Classification*

For the purpose of the book, adhesives have been divided into two main classes: structural adhesives and flexible adhesives. The distinction is a convenient one and commonly recognized in the industry, though it is not strictly logical and cannot be reduced to quantitative definition.

For practical purposes a structural adhesive is one which produces bonds capable of bearing an appreciable and sustained load for the period of service, without significant creep or other loss of performance. In the nature of things these bonds are likely to be comparatively rigid, though not necessarily to the point of becoming completely hard and brittle.

Flexible adhesives, on the other hand, produce bonds which allow a certain amount of relative movement between the adherends, or alternatively flexing of the whole assembly. In the circumstances of their use they are not normally subject to high or sustained stress, and their load-bearing properties are therefore not of primary importance.

As a general rule modern structural adhesives are based on synthetic resins, flexible adhesives on natural or synthetic elastomers. In practice, however, many structural adhesives contain a proportion of elastomer to keep them from being too brittle, and many flexible adhesives have an admixture of resin to improve specific adhesion.

There is also at least one class of adhesives, the epoxy-polysulphides, where something approaching an even balance between resin and elastomer produces a material which can reasonably claim to be both flexible and load-bearing. Conversely there are adhesives with widespread uses, particularly in the packaging industry, which cannot be said to have either of these properties.

In spite of these anomalies, however, the classification is a useful one, since it coincides with a number of distinctions arising naturally both on the manufacturing side of the industry and among the uses to which its products are ultimately put.

*Definition of 'adhesive'*

The definition of the word 'adhesive' itself is again not fully logical. Generally speaking one takes it to refer to a material used to join two solids together by forming between them a thin layer which sticks to both. At some stage in its application the adhesive must be liquid or at least plastic. When the bond is formed it is solid, though it may or may not be flexible.

By this definition, however, a number of materials would be included which one does not normally think of as adhesives. Of these the two most important groups are the solders, brazes and welding materials which for centuries have been used for bonding metal, and the hydrophilic cements such as portland cement and mortar. Both of these groups of bonding agents have a long-standing technology of their own which is already well documented, and lies outside the scope of the present volume.

The remaining field of adhesives, in the common acceptance of the term, is mainly, though not quite exclusively, concerned with organic polymers – proteins, dextrins, resins, elastomers, plastics – which are melted, dissolved or emulsified to produce the necessary liquid stage, or else used in low-molecular form and polymerized *in situ*.

A single material, however, is rarely used alone. Most practical adhesives are mixtures of one or more basic polymers with a number of other chemicals designed to modify their behaviour either in application or in service.

### *Adhesive formulation*

In spite of the large amount of fundamental research which has been undertaken in the past fifteen or twenty years, no general theory of adhesion has yet emerged. The fact that two materials stick together may on occasion be simply the result of a mechanical interlocking of surface irregularities. More frequently, molecular forces – covalent, electrostatic, van der Waals – appear to be at work, though it is often far from clear exactly which. Sometimes, but by no means always, there is a chemical reaction between adhesive and adherend, and sometimes surface impurities such as a layer of oxidation may play a part.

It is largely for this reason that the design of adhesive formulations is still carried out very much on a pragmatic basis. Textbook knowledge is useful, but new variations have to be systematically tested by experiment, and in the last instance skill and experience count for more than data sheets.

In many proposed applications where the circumstances are not particularly critical, the user's requirements can be met by a standard formulation, and this will obviously save trouble all round. On other occasions, particularly where new ground is being broken, or on large-scale applications where the bonding process has to fit into the pattern of an overall production line, it may be worthwhile having a special formulation designed to meet specific requirements.

In either case, the engineer should give the adhesives manufacturer full particulars of the job, and be prepared to collaborate closely with him in joint design and methods of application as well as in any series of tests which may be necessary to develop and prove a suitable bonding system. Moreover, since formulations differ from one manufacturer to another, and with them details of performance and other characteristics, the user should always follow scrupulously the instructions on use and on methods of handling provided by the manufacturer of the particular product he is using.

*Choosing an adhesive*

From the user's point of view, the considerations involved in choosing an adhesive fall into four main groups. There is first the nature of the adherends – the actual materials to be joined – and obviously it will be necessary to find an adhesive which will bond to both.

Secondly there is the kind of bond required, whether structural or non-structural, rigid or flexible; the bond-strength needed; the service conditions – temperature, moisture, dynamic stresses, etc – to which it will be exposed, and the service life expected.

Third there are the processing requirements – preparation of surfaces, methods of applying the adhesive, positioning of joints, use if necessary of heat and pressure, equipment and time schedules involved.

Finally, but by no means least important, there is the question of cost. Here the price per pound or per gallon of the adhesive itself, or even the price per square foot, is only one element. Labour costs together with overheads on specialized equipment will usually be at least equally important, and the time and factory space required for a given operation may be vital for fitting it into a continuous production line.

*Arrangement*

In the pages that follow, the plan has been first to give an account of the different types of adhesive at present available, outlining their general properties, their advantages and limitations, and their main uses. This is followed by a section on the actual use of adhesives, giving detailed information about such practical considerations as joint design, preparation of surfaces, techniques of application, mechanization and equipment, together with some account of established practice in the aircraft, automobile and other industries.

Both these main sections are divided into separate chapters for structural and flexible adhesives, and there is also a short chapter on the fire and health hazards which have to be taken into consideration wherever adhesives are employed on an industrial scale.

## Traditional adhesives

Until comparatively recently, all the available adhesives were materials of more or less immediate natural origin. None of these except animal glue is particularly strong, and none is fully resistant to water. They are not therefore of primary interest to the mechanical engineer, but a number of them are still widely used in other industries, and a short account of the most important is included here for the sake of completeness.

### *Animal glue*

Ordinary animal glue is made from collagen, a protein derived from the bones and hides of cattle or sheep, and occasionally from rabbit skins. Bones are first degreased and cleaned, then treated alternately with steam and hot water. Skins are treated with lime water, and the glue afterwards extracted by soaking in relays of hot water at increasing temperatures. The material extracted at lower temperatures is light in colour and relatively pure, and on evaporation under vacuum yields edible gelatines. Material extracted at higher temperatures is of lower molecular weight and produces technical gelatines and glues.

The solutions when concentrated and allowed to gel can then be dried in slabs to produce the traditional Scotch glue in sheet form. Today, however, it is more commonly sold as a powder, or in small cubes or 'pearls' (ie beads). In use the glue is dissolved in warm water at or below 60° C (140° F). Above this temperature degradation begins to set in, and becomes very rapid at 100° C.

Once applied to the joint and allowed to cool, the glue gets tacky, then rapidly gels, forming a firm initial bond which becomes steadily stronger over a period of time as it matures.

This rapid initial set is distinctive of animal glue and one of its chief advantages. It enables clamping time to be reduced to a minimum or even dispensed with altogether. The tacky stage is useful for sticking flexible to rigid materials such as cloth to board. The warm glue has a long pot life, and the shelf life of the dry material in dry conditions is virtually unlimited.

Bonds can be formed to most materials, provided at least one of the adherends is porous; but the glue is chiefly used with wood, paper, cardboard, leather, cloth, etc. Bond strength is rarely a problem since it is usually greater than the strength of the substrate. The glue-line is relatively brittle, but can be made flexible for purposes such as book binding by the addition of plasticizers, eg glycerol, sorbitol or sugar.

'Liquid glues', ie solutions that are liquid at room temperature, are made by the addition of chemicals that inhibit gelling; gap-filling glues by the addition of bone flour or china clay. Gummed paper is made by applying a film of glue and drying it while it is still hot; on rewetting, it softens, becomes tacky and at once starts to gel.

Animal glues have been successfully used for some thousands of years in wood-working industries for bonding furniture, musical instruments, decorative veneers, etc; and more recently for book binding, packaging, sizing and the manufacture of abrasive papers.

Their chief drawback lies in their poor resistance to water. They are not generally effective with impervious adherends such as metals, glass or plastics, and they are susceptible also to biological attack from mould growth and vermin.

Fish glues are made mostly from the skin and bones of cod, and resemble animal glues except that they are liquid at room temperatures. In wood-working they have been largely replaced by liquid animal glues, but they are still used to some extent in the packaging industry.

*Casein and other protein glues*

Casein is obtained from skimmed milk by precipitation with acid, and the glue is prepared by dissolving the casein in various aqueous alkaline solvents. It is usually sold as a powder, which has to be mixed with cold water before use. Since it is not itself tacky, joints normally have to be bonded under pressure.

Casein glues have fairly good bond strength to porous materials, and most of them, especially those made with sodium hydroxide, have rather better resistance to water than animal glues. Moreover they recover their original strength on redrying. They are used to some extent in the wood-working industry, especially for making plywood, and they have applications in paper coating and in bonding paper, leather and cloth.

Albumin derived from animal blood can be treated with alkalis to produce a glue which has fairly good water resistance and is still occasionally used for the manufacture of plywood. Protein glues are also produced from soya bean residues after the extraction of the oil.

*Vegetable adhesives*

Most adhesives of vegetable origin are based on starch (the simplest example being the ordinary flour paste of the Victorian nursery), or on dextrin, which is derived from starch by heat treatment with or without the presence of acid.

They are supplied either as powders to be dissolved in water, or ready mixed in liquid form. They have relatively low bond strength and poor resistance to water and to mould growth, and their main use is for paper or cardboard.

Natural gums exuded from trees are no longer of great importance as adhesives. Gum arabic, from acacia, is still used for postage stamps, gummed labels and a few other specialized applications. Gum rosin from pines, also called colophony, serves either as a solution or as a hot melt adhesive for sticking labels on tins. Canada balsam, from a North American pine, provides an optical glue with a refractive index similar to glass for sticking lenses together.

*Mineral and inorganic adhesives*

Bitumen, whether derived from native asphalt or (more frequently) as a by-product of oil refining, can be used as an adhesive in solution, in emulsion, or as a hot melt. It is of low bond strength and necessarily dark in colour; but its relative cheapness and impermeability to water have led to many applications in the building industry, including the manufacture and attachment of roofing felts, the laying of cork and other flooring finishes, the fixing of tiles and mosaics, and the bedding of hardwood blocks. Both by itself and blended with various kinds of elastomer it is extensively employed as a sealant for joints in roads and other concrete structures, and to a lesser extent in automobile manufacture.

A wrapping material made of paper, coated or laminated with bitumen, and often reinforced with a loosely woven scrim, was once widely used for waterproof packaging, but has now been largely superseded by plastics films.

Sodium silicate or water glass, which is actually a soluble glass, provides an inexpensive colourless adhesive still frequently used in packaging, especially for making corrugated cardboard, for laminating aluminium foil to paper, and sometimes also for low-grade plywood. The bond strength is relatively high, but water resistance is limited. It has, however, good temperature resistance, and can be used for the attachment of insulating materials such as asbestos and mica and as a bonding agent for foundry moulds. Potassium silicate is more expensive but has a slightly higher bond strength.