

Handbook of Adhesive Bonding

EDITED BY

CHARLES V. CAGLE

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Preface

It is difficult to single out a product or service that is not in some way affected by the adhesive industry. If a product has not come in contact with adhesives in its manufacture, it has in packaging, transportation, display, storage, advertising, etc. The adhesive industry of today stands as a monument to those people who just a few short years ago staked their reputations on the adhesive-joining concept. These were men of action, not of reaction, and each adhesive success today is a tribute to this handful of optimists who promoted another aspect of the American industrial dream and performed beyond their call of duty to create another industrial giant. To these men who believed and pursued those beliefs when faced with chaotic failure, this book is dedicated. No attempt will be made here to single out individuals among so many. Some are well known to this discipline; however, others are virtually unknown or totally forgotten. Every individual whose work is presented in this book has influenced the adhesive world—but there are many more. These men were chosen for contributions to this text because each was knowledgeable in his particular function and also because they were for the most part fundamentalist. They have not been so much concerned with why certain phenomena occur as they have been totally involved in the processes that promote these positive occurrences. A good adhesive man is like a good football coach; he can never isolate, and certainly he cannot forget, the basic fundamentals.

The views and ideas expressed here are those of the author, and no attempt has been made by the editors in any manner to alter the contributors' work. The combined effort of this text offers the reader in excess of 500 years' sum total of personal experience. There are

others who would have been welcomed to this project but who for various reasons or commitments could not participate, and many who did not generate a chapter for this book contributed much. To those this writer owes a debt of gratitude.

This book is by no means an attempt to cover the entire industry, because that would possibly require twenty books this size. It was also known there would be a certain amount of duplication in this effort, but attempts were made to keep that to a minimum.

It is a real experience to work with the many able people involved in a project such as this. I wish especially to thank James W. Roder, who taught me a couple of things about fish glue. Did you ever hear of someone using an outboard motor for mixing, chopping, and blending?

I wish to say a sincere "thank you" to all those who made my own dream become a reality.

Charles V. Cagle

Introduction

The adhesive revolution is surely in full swing in this modern space age. However, a cursory study of history is enough to show that if this is not the earliest form of joining, it is one of the older techniques. Adhesives were not seriously considered as structural bonding agents until the 1940s, when the aircraft industry promoted their usage, primarily out of sheer necessity. Before this they were utilized in nonstructural applications. In the last two decades, adhesives in a variety of forms have replaced the use of screws, rivets, welds, nails, pegs, bolts, thread, clamping, soldering, and brazing in many fields; and if the list continues to grow until 1980, adhesives will dwarf present consumption. At present, few industries are untouched by this trend, but there remains ample room for extensive growth.

ADVANTAGES

When one surveys the many uses of adhesives, the question always presents itself as to what factors influence a choice to use adhesives, and what design principles dictate the type of adhesive for a particular application. A few of these advantages are worthy of mention, accompanied by some prime examples of successful case histories.

Allows Fabrication of Smoother Parts and Assemblies Adhesives do not break through or deform the surface of an assembly or product. This is important aerodynamically for exterior use on aircraft, missile structures, spacecraft, etc., because the reduction of drag permits a smoother flight and also reduces the temperature factor. It is also advantageous for such items as electronic or electrical equipment when

close tolerance or sliding fits are necessary or desirable. It is important for use in kitchen cabinets, furniture, and home building because exposed surfaces are not defaced and contours are undisturbed after manufacture, which also eliminates costly filling operations, e.g., sanding or grinding, heavy coatings, or paint cover-up. Elimination of detail work is a time-saver.

Two strong points are made for the use of adhesives in Fig. 1. An anodized-aluminum heat sink is bonded to a circuit board (epoxy-glass). In this case adhesive flash could absolutely not be tolerated, cleanup is virtually an impossibility, and the heat sink must also be

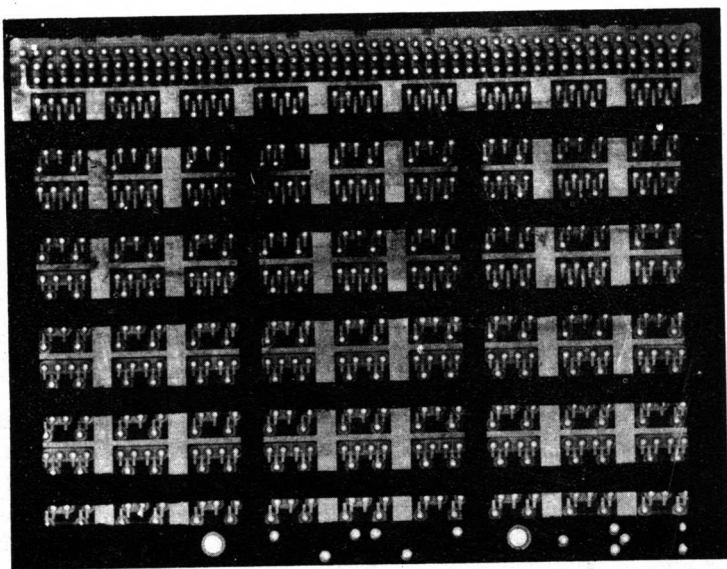


Fig. 1 An anodized-aluminum heat sink bonded to a circuit board. (*Hughes Aircraft Co.*)

perfectly located. Figure 2 illustrates the smooth-contour principle as applied to a helicopter rotor blade (being inspected ultrasonically). Not only are the surfaces smooth, but the structure is stronger because the necessity of drilling holes for mechanical fasteners has been eliminated.

Permits Use of Lighter-weight Materials Adhesively joined sheets do not fail in bearing; on the contrary, their full strength may be realized. Because the entire area is attached, adhesives tend to minimize and distribute the stress concentrations that commonly occur with screws, bolts, rivets, and welds. Uniform load distribution provides greater strength and rigidity in the assembly, which again permits the use of lighter-weight materials. This factor is also important in the design of airborne vehicles. The modern jet transport utilizes thousands

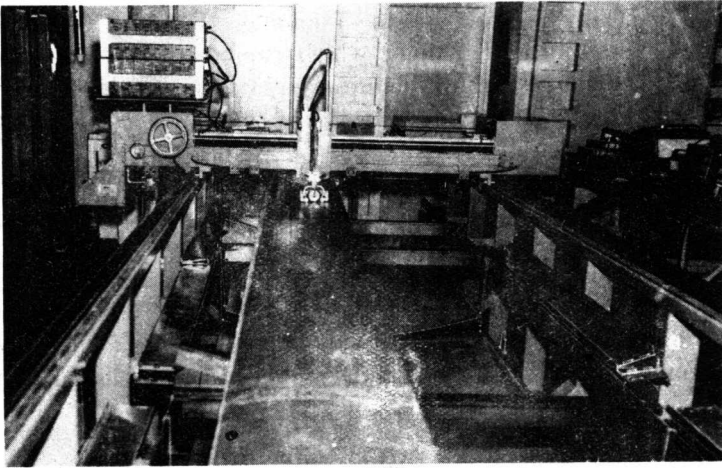


Fig. 2 A helicopter blade that has been adhesively bonded and is being ultrasonically inspected.

of square feet of honeycomb-bonded sandwich panels, a tremendous weight reduction and thus an increase in pay load. If the adhesives used today were eliminated from the space programs, the result would be chaos. Figure 3 is a good example. This is a panel for a micrometeoroid-detection satellite. This assembly would have been difficult

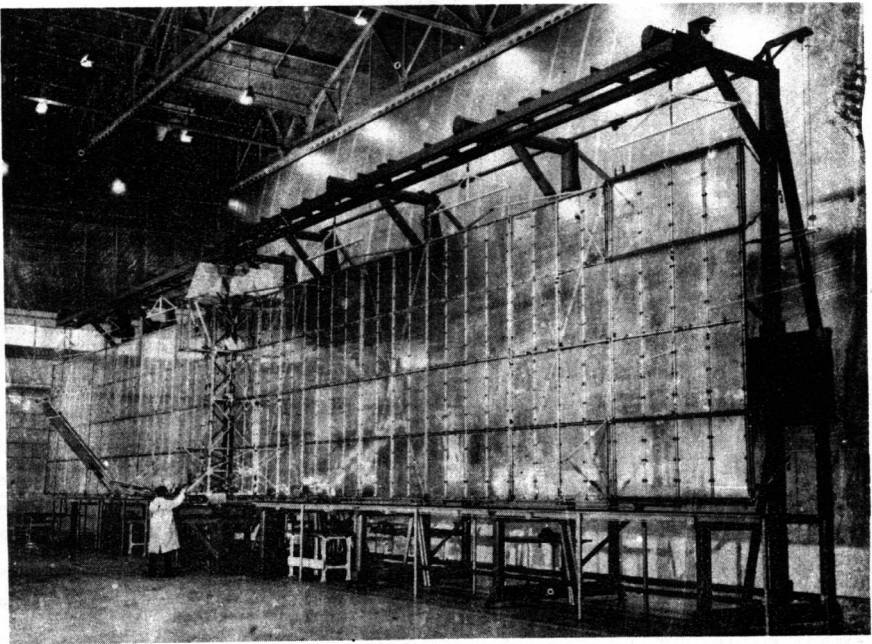


Fig. 3 A panel for a micrometeoroid satellite. (*Fairchild-Millie Corp.*)

to fabricate with any other form of joining. Figure 4 shows a light-weight air-to-air heat exchanger which capitalizes on weight savings. The weight factor also allows lighter-weight home products, appliances, autos, boats and marine equipment, and hundreds of other products where weight saving is important.

Serves as a Vibration Damper Better stress distribution also means better fatigue resistance under vibration loads. Adhesives are capable of transferring, distributing, and absorbing stresses that often cause fatigue and failure in base materials. This characteristic is especially important in automobiles, boats, and aircraft, or any other product that is constantly subjected to severe vibration and shock. For example, the average washing machine in the home has a minimum of twenty

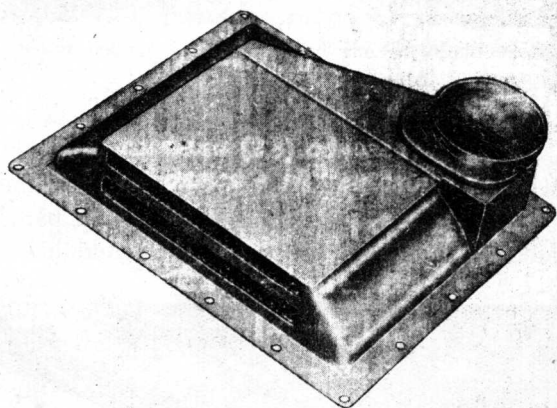


Fig. 4 A heat exchanger that is adhesively bonded. (*Armstrong Adhesive Products.*)

adhesively bonded components which are subjected to extensive vibration. This feature of adhesives has improved home products and appliances more in the last decade than any single contributing manufacturing process, especially from a cost standpoint, because less maintenance is required during the life span of the product.

Adhesives offer outstanding characteristics in shock and impact resistance. This is important not only to the average consumer but also to the industrial world; e.g., plastic tooling is a big consumer of adhesives (note that the word "adhesive" has taken on a much broader scope and is used today in lieu of terms such as resins, sealants, glue, and coatings). Tooling is subjected to a tremendous amount of punishment. For many applications the cast tooling works well, and it is unbeatable from a cost standpoint. Figure 5 shows a cast tool-die section, and Fig. 6 shows the tooling setup and a part being removed.

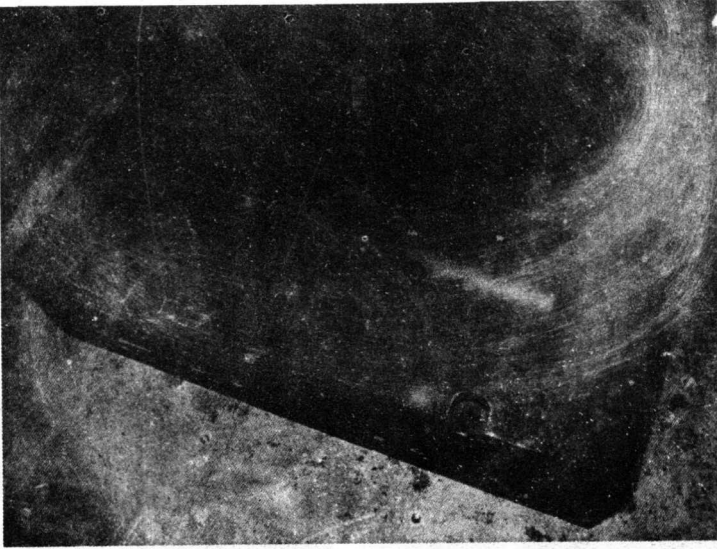


Fig. 5 Cast tool die. (*Magnolia Plastics.*)

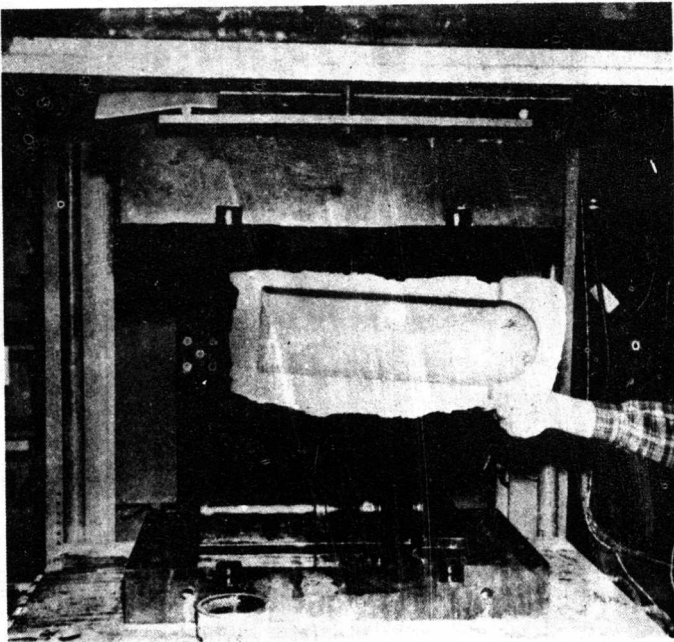


Fig. 6 A molded part being removed from cast tool-die setup. (*Magnolia Plastics.*)

Joins Dissimilar Materials In all probability this is one of the best single arguments for the use of adhesives, because many times corrosion problems caused by the electromotive-series relationship occur when dissimilar metals are joined by conventional methods. An adhesive layer isolates the two joined materials, thus practically eliminating this problem. Adhesives provide a satisfactory method for joining metals to plastics, wood, ceramics, and various other combinations of substrates. Figure 7 shows a bonded window for NASA's Apollo spacecraft that was naturally subjected to hot and cold cycles during operation. The adhesive-bonded joint (or seal) allows adequate movement (a silicone)



Fig. 7 Adhesively joined window for Apollo spacecraft. (*North American Aviation.*)

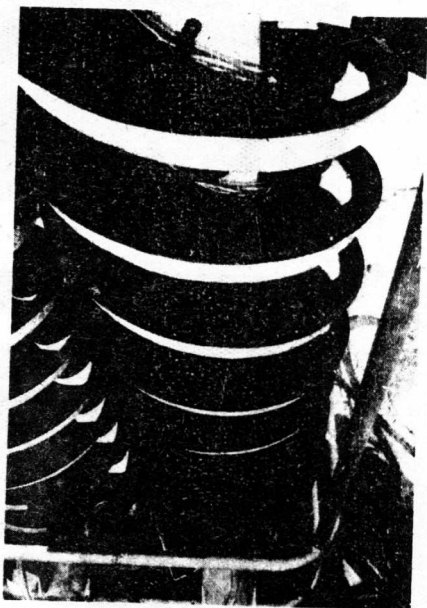


Fig. 8 A mining sieve made from polyester fiber glass and rubber that replaced a huge, heavy cast-iron unit. (*Carpo Engineering.*)

so that warpage due to temperature changes does not occur when two dissimilar materials are joined.

Figure 8 illustrates a situation that gives little choice but the use of adhesives. First, the adherends are dissimilar (polyester fiber glass and polyurethane). Second, it must effect a seal as well as a bond. Third, the unit is an extreme situation involving compound curves. Fourth, this light fiber-glass piece of mining equipment replaces a huge cast-iron affair that weighed ten times the plastic/rubber unit.

The advantage of adhesives for joining dissimilar adherends and providing for movement due to thermal expansion because of rapid temperature changes is exemplified by ducting for air conditioning. Another

ideal example is the attachment of glass windows to metallic frames in autos, homes, etc., especially in climatic areas that experience vast temperature changes. This factor is also demonstrated in delicate cameras, ovens, heating units, binoculars, television and radio, etc. Where dissimilar materials are to be joined, adhesives certainly are due prime consideration, especially if temperature fluctuations are present.

Permits Easier Fabrication of Unique Contours and Miniature Components Many complex and unique contoured surfaces that would be difficult to join by other methods may be adhesively joined satisfactorily. This is especially important in complex missile and space structures, jet aircraft, and the marine industry.

There is always another approach in small contoured components, i.e., encapsulation in flexible systems (epoxy, polyurethane, etc.), which

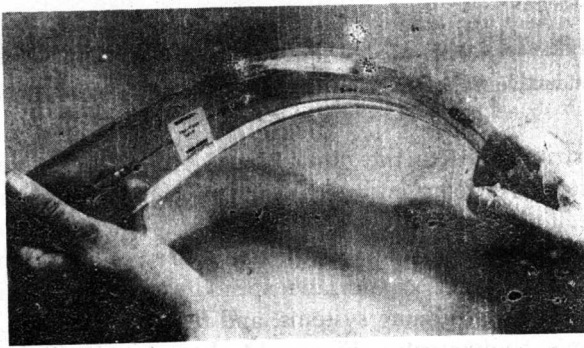


Fig. 9 Epoxy-encapsulated components, exhibiting flexibility and unusual clarity. (Tra-con Adhesives, Inc.)

not only will permit contouring but may be clear and thus easily inspected, as shown in Fig. 9. This design factor is evident in almost any adhesive-bonded product that exhibits severe contours.

The problems of joining small items such as electrical and electronic components, costume jewelry, strain gages, and wires have no other practical solution but adhesives, with the exception of some wiring where solder or silver braze would be preferred. Even a joint of this nature may be encapsulated later or wrapped with adhesive tapes. Figure 10 shows a small component where a conductive material is being applied. When tiny items are to be joined, one must consider adhesives, and when metals must be attached to nonmetals, adhesives become the only logical choice.

Acts as a Seal Since an adhesive bond is continuous, it can also seal against liquids and gases. This is an important factor in practically all phases of adhesive joining. Adhesives may also improve sound characteristics and add to the sound of hi-fis, radios, televisions, and musical instruments (where the contour factor is again important, especially

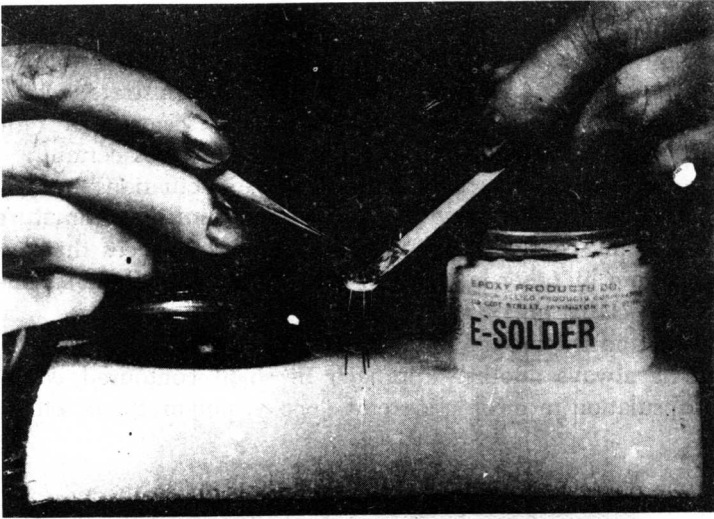


Fig. 10 Conductive adhesive being applied to a miniature component. (*Adhesive Products Co.*)

in hand instruments like the guitar and violin). Adhesives also serve as soundproofing agents and are a major factor in the installation of acoustical ceilings and walls. This is the key to encapsulation of electric motors; mounting of tubeless automobile tires; connection of sewers, water pipes, and irrigation and lawn-sprinkling equipment; manufacture of boats and air-conditioning systems; and the encapsulation of electrical and electronic components. Figure 11 shows a circuit board cast or encapsulated with a clear epoxy resin. In this case the objective is

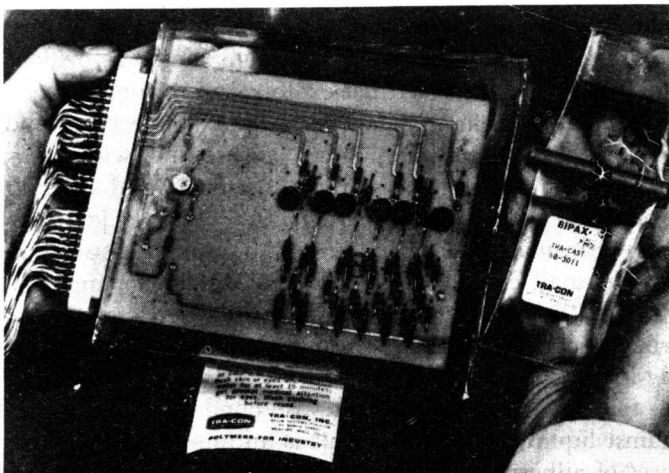


Fig. 11 A circuit board cast with a clear epoxy coating. (*Tra-con Adhesives.*)

to seal and protect the unit. However, the opposite may be true, i.e., to contain a liquid or gas as shown in Fig. 12, which is a plastic-lined acid pump. Naturally, metal protection is an objective, as well as effecting a seal.

This property of adhesives is used in the medical and dental professions. To effect a seal against bacteria, thus preventing further decay, is the objective of a dentist in applying a dental restorative. The medical profession utilize adhesives in surgery, heart pacemakers (the patient is dependent on the seal for his very life), the rebuilding of bones, and orthopedic correction devices.

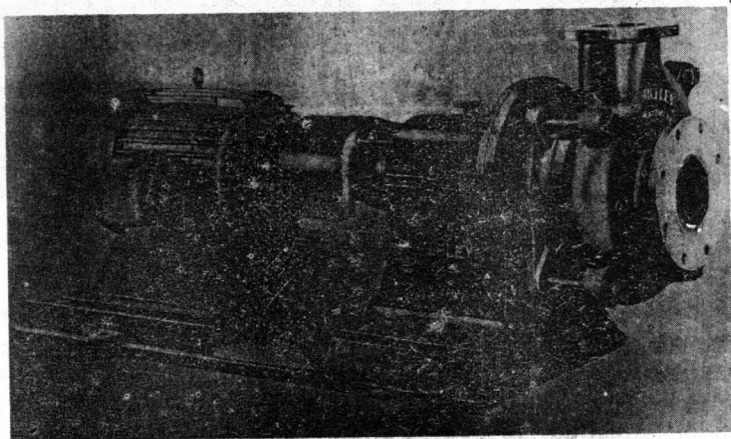


Fig. 12 A plastic-lined acid pump which promotes protection from corrosion as well as effects a seal. (*Armstrong-Products Co.*)

The sealing effect is important in all phases of adhesive bonding, because of the protection it offers to the adherends, especially metals. Figure 13 illustrates this in two ways. The specimens shown are made of magnesium and have been subjected to salt-spray conditioning. First, note that coupons A and D have adequate protective coatings to guard against salt-spray corrosion. Second, note that all coupons are not as badly degraded in the joining area. This is one of the better examples of strength as well as environmental protection, and if no other advantage dictates the use of adhesives, this one must be considered.

May Be Used as an Insulator or Conductor With the proper adhesive a joint may become an effective insulator or a system may be specifically formulated to carry or transmit an electric current. Thus, the design engineer has a choice of electrical properties which allow an adhesive application under almost any electrical requirement. This may reduce corrosion problems from fluxes and acids normally associated with soldering and brazing and at the same time reduce labor costs, plus simplifying fabrication techniques. Figure 14 shows a conductive path

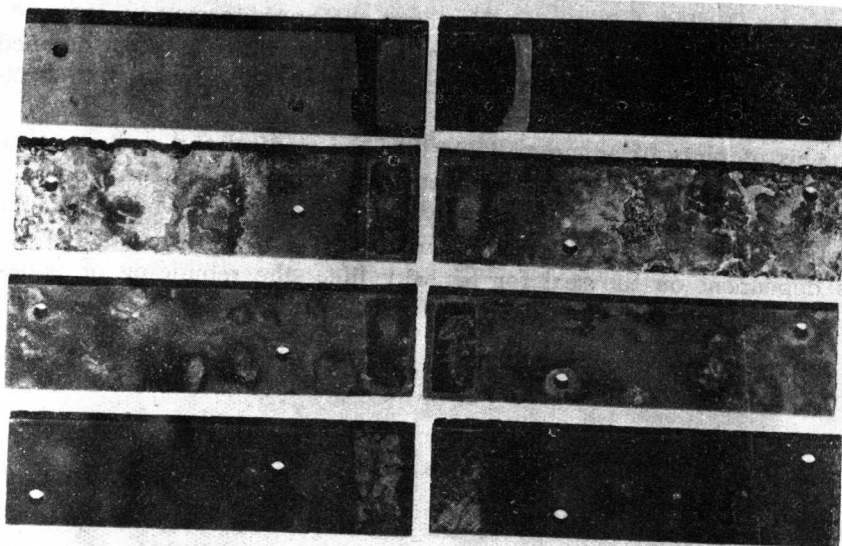


Fig. 13 Adhesively bonded and coated magnesium specimens that have been subjected to a salt-spray environment.

being made with ease on a circuit board, and this may then be entirely encapsulated with a nonconductive system if desirable. Figure 15 shows an insulator being applied to a component (during lunch hour?).

Adhesives play a major safety role in the average American home because of insulating (as well as fireproof) characteristics. Many dangerous electrical components are encapsulated in adhesives, thus confining electric currents to desired areas. This also applies to autos, boats,

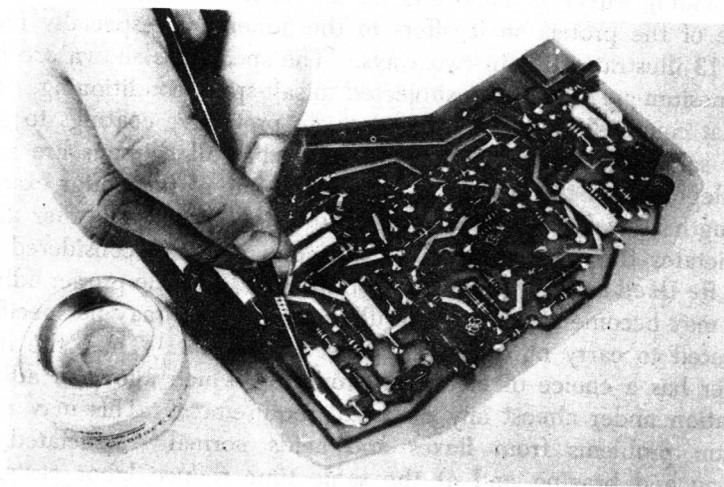


Fig. 14 A conductive path being made on a circuit board.

appliances, gadgets, toys, and hundreds of other items too numerous to mention here.

Heavy-gage Materials Bond to Thin Substrates The joining of heavy-gage metals to thin metal substrates is difficult if not impossible by modes such as welding. Rivets and bolts weaken this type of structure, and thus adhesives are the simple solution in joining metals to plastic, rubber, glass, wood, ceramic, etc. In joining foil-like materials to heavier substrates, either metal or plastic, adhesives offer the solid choice. This is also true in such items as cork and foamlike materials. Simplicity is also important in joining; e.g., where would bookbinding be today without adhesives? The flooring industry? Home paneling? Prefab housing? Last, but far from least, the hobby-craft industry?

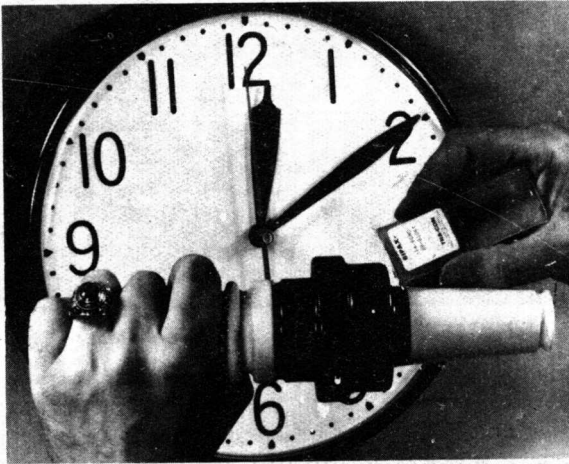


Fig. 15 An insulating adhesive material being applied to a component. (*Tra-con Adhesives.*)

Cost Reduction Cost is not the primary reason for using adhesives, but their utilization in most cases results in an economic benefit. The economy, when realized, is usually in labor costs. The liquid-type adhesives are easily automated, as shown in Fig. 16, or they may be semi-automated as shown in Fig. 17, and in many cases they are applied by hand or purchased in some type of dispensing tube.

Adhesives offer a cost saving to the homeowner in repair of household items that may be restored to useful service.

Other factors must be considered other than initial cost; e.g., the new epoxy concretes are more expensive than the older mortar-sand system. However, they are far superior in service and much stronger. Highways are being constructed and repaired with these compounds. Missile silos are being constructed and floors in manufacturing areas that must carry and support heavy traffic are being replaced with these