mixture of limestone and clay. He patented his material in 1824 and named it portland cement because he believed it resembled portland stone (a limestone building material used in England).

Today's epoxies can be custom formulated for specialized uses, large or small, in commercial and military aviation and in the electronics and automotive industries. (Photo courtesy of Magnolia Plastics, Inc.)

Also in the 19th century, the introduction of rubber and rubber-based products throughout the world brought about a new series of adhesive materials that made great impact on industry. Natural latex had been used as an adhesive by natives, but industrial processing improved its material properties for adhesive uses. Peal and Johnson received British patents in 1791 and 1797, respectively, for the use of natural rubber as an adhesive. Rubber cements — natural rubber (or more recently synthetic rubber) in a solvent — proved to be extremely water resistant and resilient.

Synthetic resins appearing in the first part of the 20th century were generally prepared from raw materials such as urea, phenolics, polyvinyl acetate and polyvinyl alcohol, melamine, resorcinol, polyester, acrylic, epoxy, and polyurethane. Synthetic resins have higher strengths and longer lifetimes than many natural adhesives. Nearly all industries found broader uses for these new and inexpensive substitutes — in automobile and aircraft manufacture, electronics, and medicine. Synthetic adhesives could join together nonporous materials such as plastics, glass, and metals with excellent bond strength unattainable with natural adhesives.

Epoxy resins were developed in the 1950s, creating an adhesive through chemical action rather than through heating, cooling, or the evaporation of a solvent. Epoxies form strong bonds to a variety of materials, including metal and glass. A resin agent containing epoxy groupings is mixed with a separate polymerizing agent just before use. The mixture solidifies into a resin that is insoluble in water and organic solvents, and that will not melt on heating. The epoxy bond shrinks only slightly on hardening, which makes epoxies particularly appropriate for large construction applications.

Epoxies can be formulated to develop hard bonds or flexible ones; some epoxies harden at room temperature, while others require heating. Metal-to-metal bonds with epoxy resins typically have shear strengths of about 3,000 pounds per square inch, though some formulations can have strengths as great as 7,000 psi under temperatures up to 350°F.

About two billion pounds of adhesives are used each year in homes and industry. Annual per capita consumption in the United States is about 40 pounds. Specialized adhesive materials have been developed in enormous variety — for dentistry, optics, electrical applications, packaging, and medicine. Some recent developments include anaerobic adhesives that set in the absence of air, delayed-tack adhesives that can be reactivated even after hardening, conductive adhesives for electrical or thermal applications, encapsulated adhesives activated by pressure, and adhesives that can withstand temperature extremes. The growth of the aircraft, aerospace, and computer industries has placed increased demands on new adhesive materials, forcing high degrees of structural strength, resistance to fatigue, and the ability to withstand exotic environmental conditions — such as deep space — far beyond anything the first users of beeswax and tree pitch could have conceived.

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