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Adhesive Joining – A Paradigm Shift For Fabrication Technique

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ABSTRACT *Mechanical joining techniques are commonly used in industries all over the world on a daily basis. A further method of joining has proven to be highly successful - Adhesive bonding. Known for thousands of years, adhesive bonding has become as important as other joining techniques as a result of the pace of developments in recent years. In many areas, this bonding technology has become a key technology. Virtually, all solid materials can be connected with one another using adhesives. This article reviews the fundamental paradigm shift evidenced in contemporary fabrication techniques as required to facilitate the emerging interest in delivering conservative alternatives.*

INTRODUCTION
Almost everything made in industry has components which need to be fixed together. Often mechanical fixing methods are used, e.g. screws, rivets or spot welds. However, engineers now often choose to use adhesive bonding. This joining technique is well proven and capable of replacing or supplementing mechanical fixing methods and has advantages which include:

- Reduced component and/or assembly costs
- Improved product performance and durability
- Greater design freedom
- Less finishing operations
- Uniform stress distribution

The basic principle of adhesive joining is that the adhesive must be in a form that may wet the surfaces of adherents and then fill the gap between the surfaces. The adhesive must then solidify, either by chemical reaction or some physical process, so that the bond may withstand the stresses in service.

HISTORICAL DEVELOPMENTS IN JOINING TECHNIQUES
The dictionary defines an adhesive as "a substance capable of holding materials together by surface attachment". This is a simple definition for a material that is the basis of a multi-billion dollar industry with more than 750 companies competing for a share of the market.

The first evidence of a substance being used as an adhesive dates back to 4000 B.C. Archaeologists studying burial sites of prehistoric tribes found foodstuffs buried with the deceased in broken pottery vessels that had been repaired with sticky resins from tree sap. The period of time between 1500-1000 B.C. gave further proof that glue had become a method of assembly. Our museums today contain many art objects and furnishings from the tombs of Egyptian pharaohs that are bonded or laminated with some type of animal glue.

The first references in literature concerning glue and the art of glue appear about the year 200 B.C. Simple procedures for making and using animal glue were written.

The next period of activity is from 1-500 A.D. when the Romans and Greeks developed the art of making animal and fish glues. Other natural ingredients were used to prepare glue, such as blood, bones, hide, milk, cheese, vegetables, and grains [1].

A study of history shows the use of glue fell into disuse until about 1500-1700 A.D., when adhesives were used in the building of furniture. Some of the greatest furniture and cabinet makers of all time used adhesives in their products.

About 1700 A.D., the widespread use of glue brought about some rapid changes in the history of adhesives. The first commercial glue factory was started in Holland to manufacture animal glue from hides.

About 1750, the first glue patent was issued in Britain for fish glue. The following decades of the next century witnessed the manufacture of casein glues in German and Swiss factories. Patents were then rapidly issued for adhesives using natural rubber, animal bones, fish, starch, and milk protein (casein). By 1900, the United States had a number of factories producing glue from these bases.

In 1910, the era of plastics began with the production of bakelite phenolic, a thermoset plastic. Within a year, adhesives using phenolic resin were put on the market. The 1920s, 1930s, and 1940s witnessed great advances in the development and production of new plastics and resins due to the World Wars. Although adhesives have been known for about 6,000 years, most of the technology of adhesives has been developed during the last 100 years [1].

The development of plastics and elastomers has rapidly advanced the development of adhesives and has given formulators a wide variety of products that can change and improve various properties of adhesives, such as flexibility, toughness, curing or setting time, temperature and chemical resistance.

APPLICATION AREAS OF ADHESIVE JOINING
Adhesives are everywhere in the highly technological manufacturing world today. Adhesive companies on-sell their products to companies in the construction sector, aircraft manufacturers, automotive manufacturers, and packaging industries. The following is a list of several commonly used adhesives and their role in industry and every-day products.

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Fish Glue: Used for photo emulsion for photo films and photo resist coatings.

Casein Glue: A waterproof adhesive used in the sealing of cigarette paper.

Starch: Used to bond paper products such as bookbinding, corrugated boxes, paper bags, wallpaper paste.

Cellulose Adhesive: The adhesive used on decals on windows and on strippable wallpaper.

Rubber-based Solvent Cements: Used on counter tops, cabinets, desks, tables, on self sealing envelopes and shipping containers etc.

Epoxies: Known and used for their excellent adhesion to metals and rigid substrates such as thermoset plastics or composites.

RTV Silicone Adhesives: Used as sealant and caulking compounds in the construction industry.

Anaerobic Adhesives: Used in any industry that needs fasteners, gaskets, bearings or any mechanical device to be sealed or secured.

Cyanoacrylates: Used in electronics for printed circuit board wires and components and on disposable plastic medical devices.

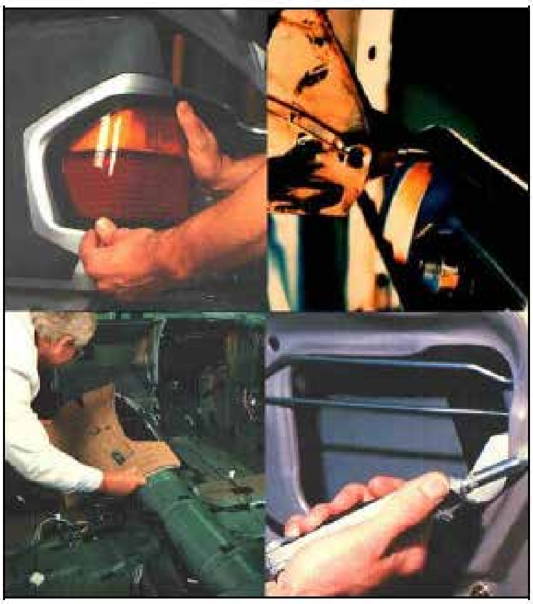

Figure 1: Adhesives in automotives

Adhesives in aerospace

Composite materials are now used across the industry, but this technology comes with new demands for structural adhesives. Furthermore, aerospace structural adhesives not only have to meet new technical specifications, but they also have to comply with tougher environmental and safety criteria.

Examples of where aerospace structural adhesives are currently being used include bonding of honeycomb sandwich panels for lightweight and rigid interior panels; core and edge filling materials for local reinforcement on primary structures and structural components; and for engine components where vibration absorption is critical and where honeycomb panel structures are used [2].

New nano-toughened epoxy paste adhesives with outstanding mechanical properties for aircraft structural metal and composite bonding and repairs now far exceed aircraft specification requirements at low, ambient and relatively high temperatures.

SPECIAL FEATURES OF ADHESIVE JOINING

The more important features of a good adhesive for metal bonding can be presented synthetically as follows:

- strength when cured meeting the requirements,
- possibly low viscosity, facilitating wetting,
- relatively low free surface energy,
- presence of various functional groups in the chemical structure of the adhesive, expanding the applicability of the adhesive and permitting the formation of chemical bonds,
- low chemical curing shrinkage rate, in the case of thermal-setting adhesives and low thermal cure shrinkage rate which permits bonding under contact pressure,
- possibility of curing at ambient temperature,
- short curing time.

A good adhesive for metal bonding should be capable of the processes of chemisorption with the material of the substrate. Its chemical structure should impart to it high cohesive strength as well as elasticity to guarantee good damping properties and ability to “absorb” stresses.

Also operating temperature is the one of the most important variable that qualifies an adhesive for a particular application. So for example, within electric motor housing, temperatures exceed the boiling point of water. At these temperatures, acrylic, urethane, and epoxy products are good candidates. Silicone and anaerobic gasketing products are used extensively to seal fluids that reach temperatures over 200°C [3]. Table 1 provides more adhesive temperature requirements.

Table 1. Temperature Constraints of Adhesive Technologies

Maximum Temperature (°C)	Appropriate Adhesives
60	anaerobic, cyanoacrylate, epoxy, polyurethane, acrylic, light cure acrylic, most hot melts
100	urethane, acrylic, epoxy
150	acrylic, epoxy, most urethane
> 150	epoxy, acrylic
> 200	select acrylic, select epoxy
230	silicone
< 370	high temperature silicones

Direct chemical exposure is typically limited to the edge of the very thin adhesive bond line. Hard or dense adhesive systems like epoxies, acrylics, and anaerobic adhesives exhibit exceptional fluid resistance and may actually be fully immersed in the fluid with minor degradation. Silicones are widely known for their resistance to non-polar solvents like gasoline and oil for sealing applications, but, may swell,

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crack, or shrink if immersed in certain solvents. Water, particularly salt water, can cause corrosion on metallic surfaces. Adhesives typically form a protective surface seal at the bond line and actually prevent corrosion from occurring.

Adhesive bonding of metals is sometimes used in special structures or operated under specific conditions for example; bonded joints in spacecraft structures, underwater repair work, bonding in electronics. In spacecraft structures, adhesive bonding is highly important due to the constant need for weight reduction. As a rule, the materials used are thin-walled, and it is also frequent to join materials with different properties. In this type of situations adhesive bonding is the only joining technology possible. Also very often in such situations the adhesives used act also as sealants, insulation materials, shock absorbing elements [4].

Adhesives for repairs in water environment are used in emergency situations, e.g. for the repair of various types of vessels or watercraft. As a rule, those are adhesives of high stickiness. In operations of underwater bonding it is important for water not to dissolve the adhesive, but also important is the opposite mechanism – it is desirable that the adhesive should desorb water from the bonding zone. Epoxies, anaerobics, cyanoacrylates, and other acrylics exhibit good resistance to water, mild acids, isopropyl alcohol, ethyl/methyl based fluids, hydrocarbons, gasoline, and oils.

A specific group of adhesives is that of adhesives for the power industry and for electronics. The power industry takes advantage of their good dielectric properties. For this reason adhesives are used not only as conventional glues but also as filling compositions and coatings with good dielectric properties. Thermoplastic adhesives have additionally the advantage that bonds made may be treated as temporary, which is extremely important in the technology of replacement of worn out or blown electronic elements [5].

For the purposes of electronics also adhesives with electric conductivity are used. These are usually cold setting epoxy adhesives with a high content of powdered silver as the filler. The more precious the material with electric conductivity used as the filler the longer the adhesive will have good conducting properties. An example of the application of such adhesives can be the repair of damaged heating system of a car rear screen. The cost element rather precludes the use of gold or platinum, hence the use of powdered silver which, additionally, has the advantage that its oxides are also good electric conductors, due to this they retain their conductivity for a long time. Adhesives with powdered aluminium as the filler tend to lose their conductivity too fast.

COMPARATIVE STUDY OF ADHESIVE JOINING [6]

	Welding	Brazing and Soldering	Mechanical Fastening	Adhesive Bonding
Joint Features				
Permanence	Permanent joints	Usually permanent	Temporary	Permanent joints
Stress distribution	Local stress points in structure	Fairly good stress distribution	Points of high stress at fasteners	Uniform load distribution over joint area
Appearance	Joint appearance usually acceptable	Good appearance	Surface discontinuities sometimes unacceptable	No surface marking. Joint almost invisible
Materials joined	Limited to similar material groups	Some capability of joining dissimilar metals	Combinations of materials can be fastened	Ideal for joining most dissimilar materials
Temperature resistance	Very high temperature resistance	Temperature resistance limited by filler metal	High temperature resistance	Poor resistance to elevated temperatures
Production Aspects				
Joint preparation	Edge preparation for thick plates	Prefluxing often required	Hole preparation and tapping for threaded fasteners	Cleaning often necessary
Post Processing	Heat transfer sometimes necessary	Corrosive fluxes must be cleaned off	Not required	Not often required
Equipment	Relatively expensive	Manual equipment cheap.	Cheap, portable and "on-site" assembly	Only multi-component dispensers are expensive
Consumables	Wire, rods, etc., fairly cheap	Some special brazing filler expensive.	Quite expensive	Structural adhesives somewhat expensive
Production rate	Can be very fast	Automatic processes quite fast	Fairly rapid	Seconds to hours, according to type

PRESENT TECHNOLOGICAL TRENDS IN ADHESIVE JOINING

Structural adhesives and structural foams are polymer solutions offering a great potential for body weight reductions. As shown in figure 2, such technology concepts allow for additional performance improvements even in already optimised body structures.

New weight reduction potential with structural adhesives and structural foams

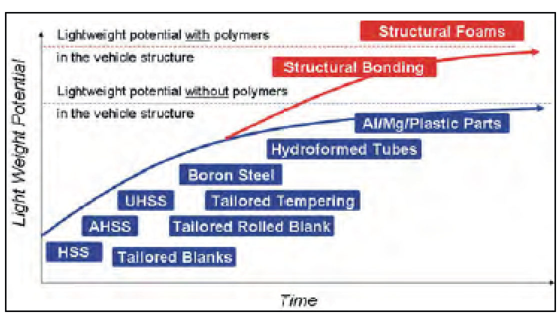

Figure 2: New weight reduction potential with structural adhesives and structural foams

Structural bonding signifies permanent and stable bonding increasing the overall efficiency and effectiveness of a conventionally joined structure. For current automotive metal bonding applications more than 95 % is based on epoxy adhesives. This is due to Structural bonding signifies permanent and stable bonding increasing the overall efficiency and effectiveness of a conventionally joined struc-

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ture. For current automotive metal bonding applications more than 95 % is based on epoxy adhesives. This is due to the combination of various advantageous characteristics such as oil absorption capacity, durability, and outstanding mechanical characteristics across a wide temperature range [7].

Structural bonding in vehicle construction is used in the following areas:

- Joining non-weldable and/or heat-sensitive components and materials.
- Construction components that are hard, or impossible to access with welding devices
- Joining various metallic and non-metallic substrates with regard to avoiding galvanic corrosion.
- Reducing cycle times and costs by reducing spot-welds

From experience, the use of structural bonding allows the following general performance characteristics:

- Increasing static stiffness between 8 and 15 %.
- Increasing dynamic stiffness by 2-3 Hz
- Increasing joint durability by 100 up to 10.000 %

Special impact resistance-modified epoxy structural adhesives also called as crash durable adhesives (CDA) yield additional load path-optimisation, thus further improving a vehicle's crash behaviour. Unnecessary performance potential can often directly be used for further reducing weight by downsizing the involved structures.

Over the last ten years, crash durable adhesives (CDAs) have developed from a regionally applied adhesive technology into a globally applied solution. They are mainly used for vehicle structures and hem flanges for closures. Their positive contributions, which have by now become known and acknowledged, have improved several car characteristics, such as higher stiffness, improved crash performance and enhanced durability. The CDA technology furthermore enables the development of lighter structures and bonding of new materials such as ultra high-strength steel or composites. Future regulations will not necessarily require the development of new formulations, as today's products already provide first-rate mechanical performance levels. The future will therefore rather be about developing materials that further improve application and processing.

CONCLUSIONS

At the conclusion of this presentation, the participants will become familiar with concepts that will challenge traditional concepts for fabrication techniques. Adhesive joining has become a prospective bonding technology in subsegments of this industry such as automotive, aircraft, and marine. Transportation adhesives and bonding processes have become increasingly sophisticated to meet the needs of today's market. This trend has been always driven by concerns about performance and durability. But more recently the focus also includes cost reduction, weight savings, durability, safety, and regulatory demands. They are routinely used in both structural and non-structural applications. In addition to their prime purpose of fastening, adhesives are also asked to do many other jobs. Depending on the application, they may need to seal, damp vibrations, be electrically insulating or conducting, provide corrosion resistance, or perform various types of other functions. Thus, this paradigm shift will ultimately result in performance improvement fabrication techniques, which reproduce the functional and esthetic properties more closely than ever before.

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