Adhesives edition 4

D.A.T.A

Adhesives, Sealants and Primers

desk–top data bank®

D.A.T.A., INC.
a Cordura Company

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A Cordura Company

Property values reported in this publication should be used as a guide to the performance of the materials, not as specification data upon which designs can be based. In all cases, we recommend that you consult with the manufacturer before final selection of the product is made.

Adhesives edition 4

Adhesives, Sealants and Primers

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Extent of Coverage

Data included in publications of The International Plastics Selector, Inc. are received from manufacturers, industry associations and government agencies in response to requests for technical information. The Publisher makes no claim of completeness or all-inclusiveness. Our thanks to those manufacturers/suppliers who provided the data for this publication.

THE PUBLISHER

PUBLISHERS'S FOREWORD

I.P.S. has actively sought out, researched, and compiled technical data from leading North American producers of adhesives, sealants and primers. This information, currently residing in our data bank, is presented here in book form as a convenient reference source. By utilizing the appropriate index(es), or ranked listing, or material class section you will be able to locate additional relevant information on the material you require.

Please read the "How to Get the Most Out of This Book" section. This will help you determine the best starting point for your search. We also suggest that you read the introductory paragraphs before each main section of the book to get a more complete understanding of how the information is presented.

The tasks of adhesive selection is often complex. In many cases, base formulations must be altered to meet specific design criteria. Also, manufacturers often ask relevant questions about the application that may not have been considered by the user. Therefore, it is recommended that prior to the final selection of any adhesive the user should contact the manufacturer and discuss the application requirements.

All of the data in this publication is in our computer data base. Please call 619/578-3910 for information on leasing magnetic tapes of the data, or on how to access and search the file via an on-line computer system.

We invite all subscribers to this publication to contact us with any new or revised industry data that can be incorporated into the next edition of Adhesives. Thank you.

How to Get the Most Out of this Book

This book is arranged and indexed to enable you to approach the data from several directions.

PAIRED SUBSTRATE INDEX

If you know the substrates you will be joining, turn first to the Paired Substrate Index. Here manufacturer's recommendations for their products have been permuted to provide an index for possible substrate pairs. This index is in alphabetical order using the first word of the pair. Thus, if you are joining ceramic to paper (or paper to ceramic), look for the Ceramic/Paper combination of the substrate index to find those commercial materials recommended for that combination. The listing gives the commercial name of the material, the adhesives class, the chemical base of the adhesive, and the page number where the data on that adhesive are presented.

(1) Locate the substrate pair (arranged in alphabetical order). "Leather/Fiberglass" will be found under "Fiberglass/Leather."

(2) Find the Adhesive Class in which you are interested.

(3) Note the Commercial Names of candidate materials.

(4) Note the Chemical Base of the candidate materials.

(5) A full listing for the material will be found on the page indicated. Turn to that page to find the complete data.

(6) A "*" beside the commercial name indicates that there is further information on that material in the Metal and Plastic Substrates Chart (which starts on page A-113).

Commercial Name	Chemical Base	Page
Asphalt/Metal		
Flexhane	Polyurethane	276
Gold Label Flex	Polyester	277
(1) **Asphalt/Plastic**		
One Part (Solvent) (2)		
(6) * DAP 977	Rubbers - Synthetic	117
One Part (Water Req'd)		
BAL-BASE 1 (3)		146
Pressure Sensitive		
DAP Weldwood Floor Tile Cement		151
Two Part (RT Cure)		
BAL-BASE 2	Acrylic (4)	186
Asphalt/Stone		
BAL-BASE 2	Acrylic	(5) 186
Asphalt/Wood		
One Part (Solvent)		
DAP 977	Rubbers - Synthetic	117
One Part (Water Req'd)		
BAL-BASE 1		146
BAL-CHEM GOLD STAR	Cement	146
Sealant - Two Pt (RT Cure)		
Gold Label Flex	Polyester	277
Ceramic/Ceramic		
Anaerobic		
Depend 330	Methacrylate	5
Imprur Product 366	Acrylic	5
Retaining Compound 620	Methacrylate	7
Retaining Compound 680	Methacrylate	7
Contact		
Aremco-Bond 570	Elastomer Mod. Phenolic	18
Crystalbond 509	Unspecified Polymer	18
Crystalbond 555	Unspecified Polymer	18
Crystalbond 590	Unspecified Polymer	18
DAP China & Glass Mender	Polyvinyl Chloride	19
DAP Household Cement	Nitro Cellulose	19
Cyanoacrylate		
Alembic OS 414	Ethyl Cyanoacrylate	28
Alembic OS 495	Ethyl Cyanoacrylate	28
Aron Alpha Type 201	Ethyl Cyanoacrylate	40
Aron Alpha Type 203	Ethyl Cyanoacrylate	40
DAP SUPER GLUE FOR WOOD & LEAT	Cyanoacrylate	29
Ethyl Blue Cap 202	Ethyl Cyanoacrylate	32
Ethyl Blue Cap 732F	Ethyl Cyanoacrylate	32
Ethyl Green Cap 203	Ethyl Cyanoacrylate	32
Ethyl White Cap 201	Ethyl Cyanoacrylate	32

Metal and Plastic Substrates Chart

This section presents information about various adhesives that will bond metals and plastics. Adhesives identified with an asterisk (*) in the Paired Substrate Index are listed by adhesive class and commercial name, followed by an identification (•) of the specific metal and generic type of plastic that the adhesive will bond.

ADHESIVES

ADHESIVES METAL AND PLASTIC SUBSTRATES CHART		METALS																			PLASTICS																
Adhesive Class / **Commercial Name**	Mfr/Supplier	Carbon/Steel	Stainless Steel	Non-ferrous	Aluminum	Beryllium	Cadmium	Chromium	Copper, Brass	Germanium	Lead	Magnesium	Nickel	Platinum	Tin	Titanium	Tungsten	Uranium	Zinc	Other Metals	Thermoplastics	Thermosets	ABS	Acetal	Acetate	Acrylic	Epoxy	Nylons	Phenolic, Ureas	Polyethylene	Polyimide	Polypropylene	Polysulfone	PVC	Styrene	Urethane	Other Plastics
Contact **Ray-bond R-82016**	Page: 23 Raymark Corp	•	•		•										•				•	•		•					•		•							•	
Cyanoacrylate **Alembic OS 414**	Page: 28 Alembic Chemicals	•	•	•				•	•			•	•								•	•	•	•	•	•	•	•	•				•	•	•	•	•
Cyanoacrylate **Alembic OS 416**	Page: 28 Alembic Chemicals	•	•	•				•	•			•	•								•	•	•	•	•	•	•	•	•				•	•	•	•	•
Cyanoacrylate **Alembic OS 420**	Page: 28 Alembic Chemicals	•	•	•		•		•	•			•									•	•	•	•	•	•	•	•	•				•	•	•	•	•
Cyanoacrylate **Alembic OS 424**	Page: 28 Alembic Chemicals	•	•	•				•	•			•	•								•	•	•	•	•	•	•	•	•				•	•	•	•	•

① CONTACT

ADHESIVE CLASS

COMMERCIAL NAME	② GC-3001	Scotch-Grip 1357	Scotch-Grip 1390	Scotch-Grip 2210	Scotch-Grip 2215	Scotch-Grip 2218
MANUFACTURER/SUPPLIER ③	Goal Chem Sealants	3M Company	3M Company	3M Company	3M Company	3M Company
CHEMICAL BASE ④	Rubbers - Synthetic	Nitrile	Chloroprene	Chloroprene	Chloroprene	Chloroprene
SPECIAL FEATURES ⑤	High bond strength Resists oil, gas, fuel Corrosion resistant	High performance Long bonding range Exc initial strength	Lower solids than 1357 Good bonding range Exc initial strength	Fast drying High initial strength Exc water & oil resist	Fast drying Rapid str build-up Aggressive tack	High ultimate strength Rapid str build-up High softening pt Exc resist to flow
SUBSTRATES ⑥	Elastomer Metal Glass Plastic	Elastomer Textile Metal Wood Glass Paper	Foam Plastic Metal Wood Sandwich	Elastomer Textile Metal Wood Plastic	Elastomer Textile Metal Wood Various	Metal Wood Sandwich Wood Various
APPLICATIONS/USES ⑦	Aircraft Industry Topcoat for fuel tanks	General Industrial Decorative uses	General Industrial Insulated sandwich pts	General Industrial Decorative laminates	General Industrial Decorative laminates	General Industrial Decorative laminates
SPECIFICATIONS		⑧ MIL-A-1154C MIL-A-21366		MIL-A-1154C MIL-A-21366		MIL-A-1154C
PROPERTIES ⑨ Color	Red or amber	Gray Green, Olive	Gray green, Olive	Yellow	Lt yellow	Green
Weight lbs/gallon *kg/liter*	6.17 *0.739*	6.80 *0.815*	6.80 *0.815*	6.90 *0.827*	6.60 *0.791*	6.60 *0.791*
Viscosity, Brookfield cps		225	50	600	240	240
Solids Content, %	20.0%	25.0%	18.0%	23.0%	19.0%	19.0%
Form	Thin syrup	Thin syrup	Thin syrup	Thin syrup	Thin syrup	Thin syrup
Application Procedures	Brush,Roll	Spray,Brush	Spray	Brush,Trowel,Roller	Spray	Spray
Flash Point °F *°C* ⑩		-14.0°F *-25.6°C*	-14.0°F *-25.6°C*	-14.0°F *-25.6°C*	-14.0°F *-25.6°C*	-14.0°F *-25.6°C*
Solvents		Ket,Ar,Al	Pet,Acn,MEK	Ket,Ar,Al	Ket,Ar,Al	Ket,Ar,Al
Storage Condition time/°F						
Open Time at RT		1 hr			1 hr	1 hr
Cure Conditions #1 time/°F/psi	10 min [a]/77.0/-	2 day/77.0/-	20 day/77.0/-	20 day/77.0/-	14 day/77.0/-	14 day/77.0/-
Cure Conditions #2 time/°F/psi						
Service Temp Range, °F low to high	-100 to 250					
Test Substrate		Birch	Birch	Birch	Birch	Birch
Lap Shear Range, psi low to high		160 to 960	160 to 960	40.0 to 550	40.0 to $1.06x10^3$	40.0 to $1.06x10^3$
Footnotes ⑪	[a]Drying time between coats		[a]Canvas/Steel			

If you know the adhesive class and commercial name of an adhesive or sealant (or have been led to it by one of the many indexes in the publication) you can find all of the available information for that adhesive in the Characteristics Section. More than 3000 products are listed, first all the adhesives and sealants, then the primers. There are twelve adhesive and sealant classes (hot melt, contact, one part solvent, film, etc.), with all adhesives in any given class and all sealants in any given class presented together. Thus, if you are interested in a hot melt adhesive, you will find all the hot melt adhesives presented together, and you will be able to make comparisions between them. Within each adhesive class, the materials are grouped alphabetically by manufacturers.

The information on each adhesive is divided into two general blocks - the descriptive header and the engineering characteristics section, which lists in English and metric units the data that will help determine whether the adhesive meets your requirements. The information listed varies for each adhesive class. The data, in general, covers such items as density, flash point, percent solids, continuous service temperature, storage conditions, solvent, etc.

(1) Adhesive Class

(2) Commercial name of the material

(3) Manufacturer/Supplier - listed alphabetically

(4) Chemical Base

(5) Manufacturers' suggested special features of the material

(6) Manufacturers' recommended substrates

(7) Manufacturers' suggested industrial application & typical uses

(8) Compliance to applicable material specifications

(9) Characteristics - designed uniquely for each adhesive or sealant class

(10) Property values reported in English and metric units

(11) Footnotes, which generally refer to peculiarities of a specific test parameter

RANKED PROPERTIES

For aid in choosing a specific property characteristic or range, these listings group together specific property values by ascending order and by the identical generic class.

(1) The material class
(2) Property value in ascending order
(3) Commercial name of candidate material
(4) Chemical Base of the candidate material
(5) The page number on which a complete listing of the materials can be found

Glass Transition (Tg), °C

Value	Commercial Name	Chemical Base	Pg	Value	Commercial Name
	Contact ①				One Part
275	Prima-Solder IH 8000	Polyimide	18	45.0	Epo-Tek 394
	Film (Supported & Unsupported)		⑤	180	Quatrex 5010
145	Amicon TG-86	Epoxy ④	44		Pressure
152 ②	Amicon TG-86TC	Epoxy	44	-56.0	Valtac P-16
162	XEA 9680 ③		47	-55.0	Valtac AT 200
177	XEA 9673	Epoxy	47	-55.0	Valtac ATS-2000
	One Part (Curing)			-55.0	Valtac 31
				-53.0	Valtac 35
-62.0	Tyrite 7411	Polyurethane	87	-53.0	Valtac 100
-3.28	EP3685	Epoxy	84	-44.0	Valtac QT
10.0	EH 7155	Epoxy	71	-39.0	Valtac 50
75.0	7077	Epoxy	82	-36.0	Valtac PA
84.0	7251	Epoxy	83		
85.0	EH 8450	Epoxy	71		Two Part (Hig
85.0	Epo-Tek H43	Epoxy	81	-72.0	7526
85.0	Epo-Tek H44	Epoxy	81	-72.0	7750-A/B
85.0	Prima-Solder ME-7650	Epoxy	72	-72.0	7754-A/B
85.0	7004	Epoxy	82	-70.0	7751-A/B
85.0	7102	Epoxy	82	-65.0	Eccolite 82-S1-VS
88.0	Epo-Tek H40	Epoxy	81	-65.0	Eccosil Gel
88.0	Epo-Tek H41	Epoxy	81	-65.0	Eccosil 4712
89.0	Thermoset ME-138	Epoxy	94	-65.0	Eccosil 5019
92.0	Ablebond 77-1	Epoxy	72	-65.0	Eccosil 5089

MATERIALS CLASS CROSS INDEX

When a specific material class is required, this index can be used to find candidate commercial names, suppliers and chemical base.

(1) The material class

(2) Manufacturer/supplier of materials in that class arranged alphabetically

(3) Commercial name of candidate materials arranged alphabetically

(4) Chemical base of the candidate material

(5) The page number on which a complete listing of the material can be found

Mfr/Supplier	Commercial Name	Chemical Base	Page
	① One Part (Emulsion) Cont'd		
Polyvinyl Chemical	NeoCryl A-5117	Acrylic	112
Polyvinyl Chemical	NeoCryl A-5118	Acrylic	112
Polyvinyl Chemical ②	NeoCryl A-5148 ③	Acrylic ④	112
Polyvinyl Chemical	NeoCryl AX-7129	Acrylic	112
Polyvinyl Chemical	NeoCryl BT-8	Acrylic	⑤ 112
Polyvinyl Chemical	NeoRez R-962	Polyurethane	112
Polyvinyl Chemical	NeoRez R-9314	Polyurethane	112
Preco	Titebond C	Polyvinyl Acetate	112
Southeastern Adh	Southeastern SEV-600	Ethylene Vinylacetate	112
Uniroyal, Inc	Royal M6102	Rubbers - Synthetic	112
Uniroyal, Inc	Royal M6107	Unspecified Polymer	112
Valchem Chemical	Valbond 300-86A	Acrylic	112
Valchem Chemical	Valbond 357-182	Acrylic	113
Valchem Chemical	Valbond 386-9	Acrylic	113
Valchem Chemical	Valbond 386-10	Acrylic	113
Valchem Chemical	Valbond 652-91	Acrylic	113
Valchem Chemical	Valbond 6002	Acrylic	113
Valchem Chemical	Valbond 6020	Acrylic	113
Valchem Chemical	Valbond 6021	Acrylic	113
Valchem Chemical	Valbond 6025	Acrylic	113
Valchem Chemical	Valbond 6053	Acrylic	113

MANUFACTURER/SUPPLIER CROSS INDEX

This index can be used to find all of the materials provided by a specific manufacturer or supplier.

(1) Name of the manufacturer or supplier arranged in alphabetical order

(2) Commercial name of the material

(3) The class for each listed material arranged in alphabetical order

(4) The page number on which a complete listing for the material can be found

Material Class	Commercial Name	Page	Material Class	Cor
	① MarChem Corp			Master Bor
One Part (Curing) ③	Mistabond S3346 ②	④ 88	Sealant - Anaerobic	Mas
One Part (Curing)	Mistaflex V9646-80	88	Sealant - Anaerobic	Mas
			Sealant - Anaerobic	Mas
	Marsh Labs		Sealant - Anaerobic	Mas
One Part (Curing)	Marsh Urethane Adhesive	88	Sealant - Anaerobic	Mas
One Part (Solvent)	Marsh ABS Cement	128	Sealant - Anaerobic	Mas
One Part (Solvent)	Marsh PVC Cement	129	Sealant - Anaerobic	Mas
Two Part (RT Cure)	Marsh Copper-Bond	225	Sealant - Anaerobic	Mas
Two Part (RT Cure)	Marsh 402	226	Sealant - Two Pt (RT Cure)	Mas
	Master Bond			Monsanto
Anaerobic	Master Bond GP2	8	One Part (Emulsion)	Gelv
Anaerobic	Master Bond GP6	8	One Part (Emulsion)	Gelv
Anaerobic	Master Bond GP6HS	8	One Part (Solvent)	Gelv
Anaerobic	Master Bond GP8	8	One Part (Solvent)	Gelv
Anaerobic	Master Bond GP10	8	One Part (Solvent)	Gelv
Anaerobic	Master Bond GP12	8	One Part (Solvent)	Gelv
Anaerobic	Master Bond GP16	8	One Part (Solvent)	Gelv
Anaerobic	Master Bond GP18	8	One Part (Solvent)	Gelv
Anaerobic	Master Bond GP20	8		
Anaerobic	Master Bond GP25	9		Nat Starcl

COMMERCIAL NAME CROSS INDEX

If only the commercial name of a material is known, this index can be used to find additional, important information.

(1) Commercial name of the material is arranged in alphabetical order

(2) Material class for each commercial name

(3) The name of the manufacturer or supplier. Principal office address and telephone numbers for each manufacturer and supplier listed are in a special section of the book.

(4) The page number on which can be found a complete listing for the material

COMMERCIAL NAME INDEX

Commercial Name	Material Class	Mfr/Supplier	Page
Epibond 1337-A/9514A	Two Part (RT Cure)	Furane Products Co	207
Epibond 1337-A/9615A	Two Part (RT Cure)	Furane Products Co	207
Epibond 1526-A/B	Two Part (RT Cure)	Furane Products Co	207
Epibond 1526-A/B ①	Sealant - Two Pt (RT Cure)	Furane Products Co	④ 270
Epibond 1534-A/B	Two Part (High Temp Cure)	Furane Products Co	167
Epibond 1539-A/B	Two Part (RT Cure)	Furane Products Co	207
Epibond 1544-A/B, A/C	Two Part (RT Cure)	Furane Products Co	207
Epibond 1545-A/B	Two Part (High Temp Cure)	Furane Products Co	167
Epibond 1546-A/B	Two Part (RT Cure)	Furane Products Co	207
Epibond 1547-A/B	Two Part (RT Cure)	Furane Products Co	207
Epibond 1548-A/B	Two Part (RT Cure) ②	Furane Products Co	207
Epibond 8543-A/B	Two Part (RT Cure)	Furane Products Co	208
Epibond 87680-A/9816	Two Part (RT Cure)	Furane Products Co ③	208
Epibond 87803-A/B	Two Part (High Temp Cure)	Furane Products Co	167
Epibond 88807-A/B	Two Part (RT Cure)	Furane Products Co	208
Epo-Tek H20E	Two Part (High Temp Cure)	Epoxy Technology	162
Epo-Tek H20S	Two Part (High Temp Cure)	Epoxy Technology	162
Epo-Tek H21D	Two Part (High Temp Cure)	Epoxy Technology	163
Epo-Tek H22	Two Part (High Temp Cure)	Epoxy Technology	163
Epo-Tek H22	Sealant - Two Pt (High Temp)	Epoxy Technology	267
Epo-TEk H27D	Two Part (High Temp Cure)	Epoxy Technology	163

CHEMICAL BASE CROSS INDEX

When a major criterion is the chemical base and the chemical base is known, this index should be used to identify candidate materials.

(1) Chemical base of the material listed in alphabetical order

(2) Material class listed in alphabetical order

(3) Commercial names of candidate materials arranged in alphabetical order

(4) Manufacturer-supplier of the listed material

(5) The page number on which a complete listing of the material can be found

CHEMICAL BASE INDEX

Material Class	Commercial Name	Mfr/Supplier	Page
	Acrylic (Cont'd) ①		
Two Part (RT Cure)	Versilok 560	Lord Corp	219
Two Part (RT Cure) ②	Marsh 402	Marsh Labs	226
Two Part (RT Cure)	Saf-T-Lok SA-4	Saf-T-Lok Chemical	236
Two Part (RT Cure)	Saf-T-Lok SA-5	Saf-T-Lok Chemical	236
Sealant - Contact	DAP Metal Mender	Beecham Home Impr	250
Sealant - One Part (Curing)	4000	Bostik/Emhart	252
Sealant - One Part (Emulsion)	Weatherban 606	3M Company	262
Sealant - One Part (Emulsion)	Royal Seal M6343	Uniroyal, Inc	⑤ 262
Sealant - Two Pt (RT Cure)	Brush-Bond	Preco	276
Sealant - Two Pt (RT Cure)	Renderoc C ③	Preco ④	277
Sealant - Two Pt (RT Cure)	Renderoc S	Preco	277
Primers	Arrow S-901	Arrow Adhesives Co	280
Primers	Arrow S-911	Arrow Adhesives Co	280
Primers	Meltbond 328-II	BASF/Narmco	280
Primers	Meltbond 329-II	BASF/Narmco	280
Primers	Meltbond 6725-1	BASF/Narmco	280
Primers	Meltbond 6740	BASF/Narmco	280
Primers	Metlbond 6726	BASF/Narmco	280
Primers	DAP Weldwood Wallcovering Prim	Beecham Home Impr	280

LIST OF MANUFACTURERS AND SUPPLIERS

You have the manufacturer's or supplier's name? The address section (pg. 393) gives the principal place of business of the 118 suppliers whose products are presented in this volume.

LIST OF MANUFACTURERS & SUPPLIERS

A

AC & E
American Chemical & Engineering Company
51 Greenwoods Road
Torrington, CT 06790
203-482-1010

AI Technology
AI Technology, Inc.
PO Box 3081
Princeton, NJ 08540
609-882-2332

AI Technology, Inc.
Rm PO2, Drawning House
145-6 Connaught Road, C
Hong Kong
5-454982

Ablestik Labs
Ablestik Laboratories
833 West 182nd Street
Gardens, CA 90248
213-532-9341
Telex: 910-346-7606

Apple Adhesives
Apple Adhesives, Inc.
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Hollis, NY 11423
718-454-7375
Telex 645004 APPLE ADHS NY
Fax 718-454-2947
Toll Free 800-221-4478

Aremco Products
Aremco Products, Inc.
PO Box 429
Ossining, NY 10562
914-762-0685
Telex 137142

Arrow Adhesives Co
Arrow Adhesives Company
5457 Spalding Drive
Norcross, GA 30092
404-448-9058

Auburn Mfg Co
Auburn Manufacturing Company
35 Stack Street
PO Box 251
Middletown, CT 06457
203-346-6677

Common Terminology

A-stage – an early stage in the reaction of certain resins where the molecular weight is low and the resin is still fusible & soluble.

Adhere – to stick or hold fast by adhesion.

Adherend – a surface which is held to another surface by an adhesive. Also known as substrate.

Adhesion – steady or firm attachment of two surfaces which are held together by interfacial forces (valence forces or interlocking action, or both).

Adhesive, Anaerobic – an adhesive that cures or sets in the absence of oxygen.

Adhesive, Contact – an adhesive that will bond to itself instantaneously upon contact and is apparently dry to the touch. Also known as contact bond adhesive or dry bond adhesive.

Adhesive, Cyanoacrylate – adhesives which have the ability to polymerize very quickly at room temperature without a catalyst due to the high polarization of the unsaturated acrylate bond.

Adhesive, Emulsion – an adhesive dispersed in a continuous aqueous phase.

Adhesive, Foamed – an adhesive which has had its density decreased by the presence of numerous gaseous cells dispersed throughout its mass.

Adhesive, Heat Activated – an initially dry adhesive which is rendered tacky or fluid by the application of heat or heat and pressure.

Adhesive, Hot Melt – an adhesive liquefied by heat for application and cooled to a solid state for bonding.

Adhesive, Pressure Sensitive – a permanently tacky adhesive in solvent-free form. This material instantaneously bonds to most solid surfaces with the application of very slight pressure.

Adhesive, Room Temperature Curing – an adhesive that cures at room temperature (20 – 30°C or 68 – 86°F). This is in accordance with the limits set for Standard Room Temperature (ASTM Method D-618, Conditioning Plastics and Electric Insulating Materials for Testing).

Adhesive, Dispersion – an adhesive system in which the resin is suspended in a liquid.

B-Stage – an intermediate stage of reaction where the material softens when heated and swells in the presence of certain liquids, but may not completely fuse or dissolve. The resin is usually supplied in this uncured state.

Bond Strength – the amount of load, applied in various ways, required to break an adhesive assembly with the failure occurring near or in the plane of the bond. The load can be applied in tension, compression, flexure, peel, impact, cleavage or shear.

C-Stage – the last stage of the reaction where the material is now relatively insoluble and infusible. Most resins in a fully cured adhesive layer are in this stage.

Creep – a change in dimension over time of the material under load preceding the initial elastic or rapid deformation. Also known as cold flow when creep occurs at room temperature.

Cure – using a chemical reaction to change the physical properties of the adhesive. The reaction can be by condensation, polymerization, or vulcanization and is accomplished by the addition of heat and/or catalyst, alone or in combination, with or without pressure.

Delamination – an adhesive failure causing the separation of layers within a laminate. The failure occurs either in the adhesive itself or at the interface between the adhesive and the substrate or because of cohesive failure of the substrate.

Elastomer – a macromolecular material that is able to recover substantially in shape and size after removal of a deforming force in a room temperature environment.

Failure, Adhesive – bond rupture occurring at the adhesive adherend interface.

Failure, Cohesive – bond rupture occurring within the adhesive.

Filler – a material (relatively nonadhesive) added to an adhesive to alter various properties such as permanence, strength, or other qualities. Fillers can also be inert, used to make the adhesive less costly.

Hardener – an additive or mixture of substances used to promote or control the curing reaction by taking part in it. The degree of hardness of the cured film can be controlled by adding a "hardener."

Inhibitor – an additive used to slow down the chemical reaction. The purpose may be to prolong storage or working life for greater application flexibility.

Laminate – two or more layers of material or materials bonded together forming one sheet.

Modifier – any chemically inert additive used to change the properties of the adhesive formulation.

Paste – a soft plastic mixture with a high order of yield value, such as that of a paste prepared by heating a mixture of starch and water followed by cooling.

Plasticizer – an additive used to increase an adhesive's flexibility, workability, or distensibility. Other changes can occur such as a reduction in melt viscosity, lowering the temperature of the second-order transition, or lowering the elastic modulus of the solid adhesive.

Polymerization – a chemical reaction where the molecules of a monomer are linked together to form larger molecules with a molecular weight being a multiple of that of the original substance. The process is also known as copolymerization or heteropolymerization when two or more monomers are involved.

Post Cure – a treatment following the initial cure, used to modify specific properties. This treatment normally involves additional heat.

Primer – a coating applied to a surface to improve the adhering properties and load performance of an adhesive.

Release Paper – a material in sheet form used to protect and/or support an adhesive film or mass, and which can be easily removed from the film or mass prior to use.

Sandwich – a composite assembly consisting of a foam or honeycomb layer laminated and glued between two hard outer sheets. The outer sheets can be alloys, plastics, wood or other substrates.

Solids Content – the nonvolatile matter in an adhesive measured as the percent by weight.

Storage Life – the length of time under specified temperature conditions at which a packaged material can be stored and remain suitable for use. Also known as Shelf Life.

Structural Adhesive – an adhesive that is successfully able to transfer a load between adherends exposed to service environments typical for the structure involved.

Substrate – a somewhat broader term than adherend. A material upon which an adhesive-containing substance is spread for any purpose, such as bonding or coating.

Tack – the property of the adhesive that enables it to bond to an adherend after coming in contact with it under low pressure.

Temperature, Curing – the temperature required for an adhesive or an adhesive assembly to result in cure.

Thixotropy – the ability of adhesive systems to thin upon isothermal agitation and to thicken upon rest.

Time, Curing – the time required for an adhesive or assembly to cure when subjected to pressure or heat, or both.

Viscosity – the measure of the resistance of a fluid to flow. Poise (or centipoise) is the absolute unit of measure.

Vulcanization – a chemical reaction occurring when sulfur or other suitable agents are added to rubber resulting in a change in physical properties such as less surface tackiness, decreased plastic flow, and increased tensile strength.

Working Life – the length of time an adhesive remains suitable for use after being mixed with a catalyst, solvent, or other compounding ingredients.

Focusing on the Requirements of the Job

In most applications, several requirements must be considered in selecting the best adhesive. Review this list of questions as a quick way to focus on the most common features and requirements of adhesive application. At each point on the list, you will find appropriate sections of the desk-top data bank® indicated.

REQUIREMENTS OF THE JOB:	SECTION IN ADHESIVES Edition 4
A. Materials to be Joined __________ to __________ (Substrate) (Substrate) ☐ Rigid ☐ Smooth ☐ Rough ☐ Flexible ☐ Permeable ☐ Impermeable	Paired Substrate Index (pg. A-35) Metal and Plastic Substrate Chart (pg. A-113) Material Characteristics (pg. 1)
B. Surface Preparation ☐ None ☐ Mechanical Abrasion ☐ Solvent Wipe ☐ Surface Etch or Treatment ☐ Vapor Degrease ☐ Primer	Introduction to Adhesive Technology (pg. A-1) Listing of Primers (pg. 279)
C. Chemical or Solvent Environment: ☐ Immersion ☐ Intermittent ☐ Vapor ☐ None ☐ Continuous	Material Characteristics (pg. 1) Definitions of Adhesive Classes (pg. A-31) Chemical Base Index (pg. 372)
D. Conditions and Requirements: 1. ☐ High Temperature Continuous _______°F Intermittent _______°F ☐ Low Temperature _______°F ☐ Room Temperature 2. ☐ Moisture Resistance ☐ Weather & Sunlight Resistance ☐ Flexibility ☐ FDA Approved ☐ Color ☐ Flash Point ☐ Odor ☐ Form ☐ Environmental Restrictions ☐ Viscosity ☐ Solids Content ☐ Tensile Loading ☐ Torque Loading	Material Characteristics (pg. 1) ASTM Test Descriptions (pg. A-23) Joint Design and Failing Loads (pg. A-6) Ranked Properties (pg. 287)
E. Application: 1. ☐ Applied by Hand ☐ Applied by Machine 2. ☐ Brush ☐ Roller Coat ☐ Spray ☐ Other ☐ Knife ☐ Dip ☐ Extrude	Material Characteristics (pg. 1)
F. Bonding Requirements: ☐ Immediate Bonding ☐ Delayed Bonding	Material Characteristics (pg. 1) Chemical Base Index (pg. 372)
G. Adhesive Class: ☐ Anaerobic ☐ One Part (Emulsion) ☐ Contact ☐ One Part (Solvent) ☐ Cyanoacrylate ☐ One Part (Water Req'd) ☐ Film-Supported ☐ Pressure Sensitive ☐ Film-Unsupported ☐ Two Part (Elevated Temp. Cure) ☐ Hot Melt ☐ Two Part (Room Temp. Cure) ☐ One Part (Curing)	Definitions of Adhesive Classes (pg. A-31) Material Characteristics (pg. 1) Material Class Index (pg. 318)
H. Project Review: ☐ New Project ☐ Existing Project Adhesive being replaced __________ Price/lb __________ Supplier __________ Estimated monthly volume __________ Special conditions and inherent problems __	Ranked Properties (pg. 287) Manufacturer Index (pg. 338) Commercial Name Index (pg. 352) Chemical Base Index (pg. 372) Material Class Index (pg. 318) Listing of Manufacturers and Suppliers (pg. 393)

Introduction to Adhesive Technology

This section of Adhesives presents a brief summary of current adhesives technology in the hope that it will be useful both as an introduction to those new to adhesives technology and as a review to those who are already familiar with it. The section includes:

Introductory Theoretical Concepts
Chemical versus Mechanical Bonding
Joint Design and Failing Loads
Surface Preparation
Application Methods
Anaerobic Adhesive Technology
Cyanoacrylate Adhesive Technology

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A. ADHESIVES AND ADHESION

Introductory Theoretical Concepts

(A. Lewis)

Adhesives are scientifically and technologically diverse subjects encompassing the fields of polymeric materials, rheology, surface chemistry, engineering mechanics and process technology. Adhesion, on the other hand, is a specific interfacial phenomenon pertaining to the degree to which the surfaces of two different materials are attracted to each other. The molecular basis of adhesion is rarely studied in practice; one resorts to secondary means of determining the forces of adhesion (contact angle, contact potential, adhesive joint strength). In particular, one must make a clear distinction between the forces of adhesion and adhesive joint strength. The latter is in the realm of engineering mechanics and is useful for engineering design purposes. Adhesive joint strength is, therefore, the most important engineering property of an adhesive material.

Several theories of adhesion exist which are based on surface-chemical phenomena:

1. The **adsorption theory** in which the attractive forces between materials are interpreted in terms of the chemisorbed and physisorbed atomic and molecular species that exist at an interface.
2. The **electrical theory** which explains adhesive attraction forces in terms of electrostatic effects at an interface.
3. The **diffusion theory** in which adhesion is attributed to intermolecular entanglements at the interface.

It is generally considered that there is no generalized, unified theory of adhesion since the phenomenon is known to exist between a great diversity of material types. In some special cases, either pure adsorption, or electrical or diffusion attractive forces are found at an adhesive-bound interface. More frequently, one finds adhesion to be a synergistic combination of all of these driving, attractive forces. This is especially true in the case of practically all adhesive bonding situations.

Several theories of adhesive joint strength exist, the most notable being the **boundary layer theory.** Here, the strength of an adhesive joint is interpreted in terms of the rheological strength of a discreet interfacial layer that exists between the adhesive material and the substrate (adherend). This theory proposes the existence of a finite boundary layer composed of adsorbed adhesive polymer molecules that differ in nature from those constituting the bulk phase. The criterion for strong adhesive joints is merely that the boundary layer be strong enough to withstand the effects of external stresses. Weak joints are caused by weak boundary layers which are in turn the result of interfaces that have: (a) entrapped air; (b) impurities of low molecular weight species that concentrate near the surface; (c) cohesively weak surface chemical layers on the adherend.

Recently, the boundary-layer theory of adhesive joint strength has been extended to yield a more quantitative interpretation. In this new theory, the boundary layer has been "quantized" in the form of attachment sites. Basically, the greater the number of effective attachment sites functioning in the boundary layer, the stronger the boundary layer becomes. At a specific concentration of attachment sites, the strength of the boundary layer becomes greater than the strength of the bulk adhesive material (or the adherend material); the adhesive joint then fails in a cohesive mode representing the ultimate functional strength the particular adhesive joint can achieve. The nature of these attachment sites depends upon the adhesive and adherend interfacial interaction. These attachment sites are proposed to be morphological entities (oriented domains at the interface) representing groups of adhesive polymer molecules rather than specific, single molecules or sets of atom surface interactions. This extension of the boundary-layer theory has flexibility in that one can not only describe the strength state of the boundary layer, but one can also, qualitatively at least, describe the deterioration of joint strength by external environments. Here, the environmental deterioration of adhesive joint strength can be explained by the destruction of attachment site entities by the external derogatory environment. Further development of this attachment-site theory in the realm of practical utility for the adhesive materials engineer is sure to take place.

An additional proposal on adhesive joint strength is the **mechanical interlocking theory.** While it cannot be denied as being a means of contributing somewhat to the strength of certain adhesive joint configurations (bonding to irregular surfaces, for example) the mechanical interlocking interpretation of adhesive joint strength is not generally applicable unless special adhesive joints designed to invoke the mechanical interlocking technique are specifically prepared and fabricated.

In dealing with adhesive materials, one must consider the adhesive joining process; it is a very important facet of adhesives technology. A great variety of methods and techniques exist for handling, applying and curing adhesives. Adhesive joining is a chemical joining process. One must work with properly prepared adherend surfaces or the chemistry of the joining process may be disrupted leading to weak and/or improperly fabricated adhesive joints and bonded structures. In each case, the adhesive materials engineer must consider the adhesive joining or bonding procedures systematically. These are: (1) characteristics of the materials to be joined; (2) joint design; (3) adhesive materials handling an application; (4) cure of the adhesive-adherend couple; (5) ultimate strength and environmental performance of the adhesively joined, fabricated art or structure.

In this systems consideration, information contained in this volume is outlined as a directory in terms of what information is furnished by adhesive suppliers. This information is cataloged in a manner that enables the adhesives application engineer to have an overview of what adhesive materials are now available, and the application and performance characteristics of these adhesive, particularly the substrates for which the adhesives are recommended by the manufacturers.

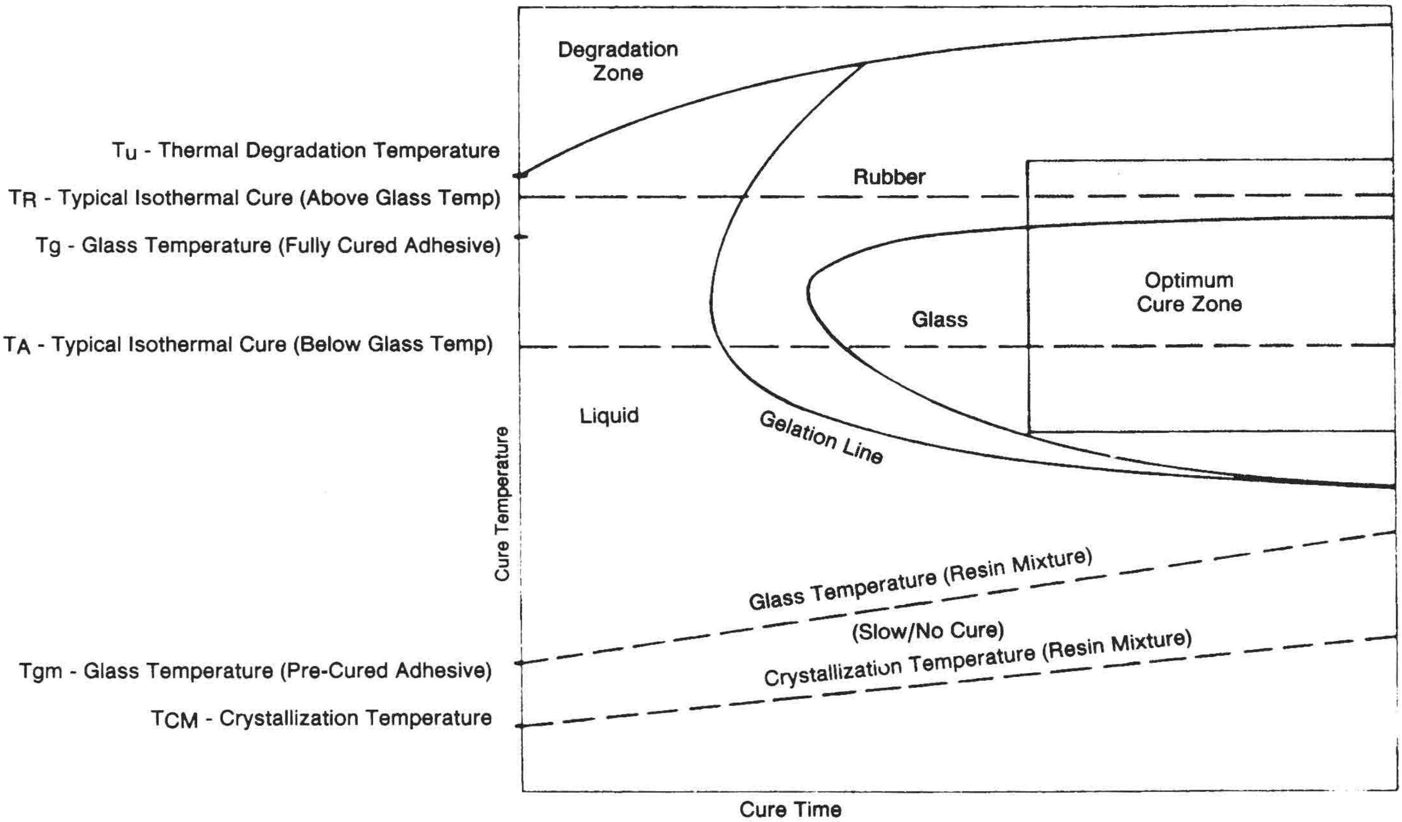
Since adhesive materials are used in such a variety of applications, many specific situations arise presenting special problems. The ultimate source of adhesives information is the adhesive supplier and the tests the user may make of his production design and system. The supplier is willing, in most cases, to assist in adhesive selection in the context of his particular product line. Furthermore, for certain applications, the adhesive suppliers can formulate or reformulate their products to accommodate any special application conditions or performance criteria the adhesives user may require.

Cure of Adhesive Materials

The cure of a resin - a most important, yet imperfectly understood phenomenon - can be defined in a number of ways. Classically, the term "cure of a resin" refers to the chemical crosslinking of a thermosetting resin or polymer. However, for adhesive materials, a broader definition can apply relative to the rheological state changes that accompany the setting or fixation of an adhesive. We shall define cure as the process involving the liquid-to-solid (gel, rubber or hard plastic) conversion of any resin or polymer system, no matter what chemical or physicochemical means is used to achieve this change in rheological state.

The mechanism of liquid-to-solid conversion in adhesives depends, of course, on the class of adhesive. In simple thermoplastic adhesives, the liquid-to-solid conversion can involve the evaporation of a solvent, as in a contact cement or pressure sensitive adhesive. In a hot melt adhesive, liquid-to-solid conversion is achieved by cooling the polymer from its molten state. Some adhesives, such as the cyanoacrylates, cure by polymerization of a liquid monomer (in-situ polymerization). In thermosetting adhesives, such as the epoxies, modified epoxies and polyurethanes, the liquid-to-solid cure transition involves chemical crosslinking.

These cure processes are often chemically and morphologically complex. A scheme to describe the state of cure of thermosetting adhesives has been developed using a dynamic mechanical method - namely, torsional braid analysis isothermal cure data. Here, cure time/temperature rheological state "phase" diagrams are constructed, giving the limits of cure time and temperature that will cause sufficient cure of the thermosetting resin. A schematic of this cure "phase" diagram is shown in the accompanying illustration.



Cure Time/Temperature Phase Diagram of Model Thermosetting Adhesive Resin System

For illustration purposes, let us assume that one wishes to understand the thermosetting cure behavior of a polyamine resin reacting with a liquid epoxy resin. Reference to the diagram shows that if one proceeds to cool the reactive amine/epoxy resin mixture down to the liquid crystallization temperature of the resin mixture, T_{CM}, the material would crystallize out; very slow or no curing (crosslinking or linear polymerization) would take place. If the temperature was in the range between T_{CM} and Tgm, the reactive mixture would be in the glassy state. Again, slow or no cure would take place. Above Tgm, (the glass temperature of the "monomeric" resin mixture) the resin mixture is in the liquid state and, depending on the temperature, the amine and the epoxy would react in a crosslinking mode. In this cure temperature range, the resin proceeds to react chemically in a measurable fashion within a conveniently finite time; the higher the temperature, the faster the cure. Under typical isothermal cure conditions, T_A, the adhesive resin material is shown to traverse a series of rheological states during its cure. First, the liquid gels, then converts to a rubber and finally into a polymeric glass. These "phase" changes can easily be followed by dynamic mechanical (and in some cases dielectric) techniques. It is in the glassy state that the adhesive resin material can be said to reach a final state of cure. In structural adhesives, ultimate joint strength is achieved only when the adhesive has crosslinked to the extent of converting itself into a polymeric glass at its functional temperature conditions. This is accomplished by having the resin reach a high degree of crosslinking.

Another cure mechanism is possible in such thermosetting resin systems. Again, reference to the figure shows that if one proceeds to cure the adhesive isothermally above the glass temperature of the ultimately crosslinked system, Tg, there are only two "phases" that the resin would traverse during cure (gelation point and rubber). This condition is shown by T_R in the figure. Here, the resin system would not convert to a glass unless it was subsequently cooled down to the glassy state - the temperature range below which the adhesive would function.

Finally, if the adhesive were cured at or above the thermal degradation temperature of the adhesive resin, T_u, improper cure and bond formation would result. This general approach shows that each thermosetting adhesive system would have a characteristic time/temperature cure zone for various adhesives. For the illustrated example, this cure zone is shown in a shaded section. From this analysis, it is evident that if the time/temperature cure profiles of all thermosetting adhesives (liquid, paste or film types) were known, a much better understanding of the cure behavior of thermosetting adhesive materials would be accomplished.

NOTE:*Torsional braid analysis (TBA), described above, is by no means the only approach to analyzing adhesive cure. Other concepts are thermomechanical analysis (TMA), thermogravimetric analysis (TGA), and differential scanning calorimetric (DSC).*

B. CHEMICAL vs MECHANICAL BONDING

(R. Gosnell)

ADVANTAGES OF ADHESIVE BONDING

PROCESSING CONVENIENCE AND SPEED

In the earliest uses of a "glue pot," the user was taking advantage of the processing convenience of joining two materials by adhesive bonding. This processing convenience remains as one of the most important features in the utilization of adhesives. While some of these early applications may have been unsophisticated, users did recognize the simplicity of joining by the application of a viscous liquid which becomes solid and develops some structural integrity.

These processing features still provide an impetus for the use of adhesives in joining. Application can be readily automated for a wide variety of forms. More advanced technology has provided a wide variety of adhesive types each offering some unique processing convenience. (See the section on adhesive types.) For example, the hot melt type can be applied as a thermoplastic formulation, which is quite fluid at elevated temperatures but solidifies on cooling to give surprisingly strong and tough joints. This approach is widely used in the packaging industry as well as in "stick" guns which have wide utility.

In some cases, a "pre-tacky condition" exists in an adhesive. This helps greatly in holding components in place until they are bonded permanently by subsequent curing.

Generally, from a processing viewpoint, no holes need be drilled, no thread tapping is required, exact mating is not essential, dissimilar materials are compatible and the simplest of application techniques is, in most cases, quite suitable.

SUITABILITY FOR A WIDE VARIETY OF SUBSTRATES AND SUBSTRATE FORMS

Flexibility of adhesives in the glue line, combined with the ability to wet a wide variety of substrates, results in general applicability to most materials. This is true for bonding A to A as well as A to B. Comments on the theory of adhesion serve to explain why most materials can be adhesively bonded. Prerequisites for a bondable surface are met by most clean surfaces. There are very few exceptions. Even in the most difficult cases, special surface preparation or primers can be used to develop an acceptable bonding surface.

This feature of adhesive bonding represents a special advantage when joining dissimilar metals, materials with greatly differing thermal expansion coefficients, or other difficult fastening problems such as films or fabrics to solid substrates.

In some cases mechanical fastening is impractical and adhesive bonding is indeed the only way to join materials - such as bonding particulate substrates or short fibers (such as flocks) to a surface.

The form or physical configuration of the substrate can vary from solid blocks to films, sheets, fabrics, composites or particles. Examples are laminated wooden beams, grinding wheels, sandpaper, laminated films, film covered slabs, cardboard boxes and flocked wallpaper. In aerospace and construction applications, it is difficult to conceive of any other fastening method which would be suitable for the fabrication of sandwich panels with honeycomb cores.

STRENGTH-TO-WEIGHT RATIO

In bonding applications where weight is of concern, the strength-to-weight ratio of adhesives offers a reduction in joint weight with no loss in physical performance (and in most cases an improvement in the overall performance profile of the joint.)

In addition, development of more isotropic materials by lamination of differing orientation of plies results in an overall improvement in the system of strength-to-weight ratio. An example is ordinary plywood.

Adhesive strength (i.e., the interfacial force) is often extremely high; it is not uncommon to have forces of adhesion exceeding the cohesive strength of the adhesive as well as the substrate. Failures occur in the substrate or in the adhesive, but not at the interface.

Most unfilled or unhalogenated adhesives weigh about 1.1 to 1.2 gm/cm^3, a value that seldom causes weight problems or restrictions.

DISTRIBUTION OF STRESS

Mechanical fastening methods require holes for bolts, rivets, screws, etc. This results in discontinuities in the substrate which become focal points for stress concentration and serve as initiating points for failure. In many structures, improvement in fatigue life of a bonded structure over a mechanically fastened structure results in a vastly improved reliable service life.

In a simple joint such as a bonded overlap, the applied load is distributed evenly over the entire lap area. This produces a joined system capable of handling the applied load as if the material were continuous.

In some cases, joining dissimilar materials by mechanical means is virtually impossible. Such is the case when attempting to mount glass or ceramics to structures. In these cases, stress concentrations on localized mechanical fastening points result in rapid catastrophic failure.

In helicopters, as well as fixed-wing aircraft, the required joining of dissimilar materials has resulted in wide acceptance of adhesively bonded structures. The aerospace industry has, consequently, been a leader in the utilization of structural adhesives. The industry has developed, in concert with certain adhesive manufacturers, several systems for honeycomb sandwich panels and beam-stiffened skins. In many circumstances, the absence of contour irregularities, such as those caused by bolts and rivets, confers an added advantage.

SEALING AND INSULATING NATURE OF THE BOND

In good adhesive joints, the glue line is continuous and fairly uniform in thickness. This results in an effective seal and may add the feature of containment or exclusion of gases and liquids. In bonding of dissimilar metals, the electrical insulating effect of the polymeric adhesive minimizes corrosion by disruption of the cathodic effect.

COST

Adhesive bonding offers a savings over mechanical bonding, not only in the cost of the actual materials for joining, but also in reduced labor requirements for processing or fabrication. Overall production cost is an exceedingly complex topic and beyond the scope of this introduction to adhesives processing.

DISADVANTAGES OF ADHESIVE BONDING

Disadvantages of the several classes or types of adhesives presented in this "desk-top data bank®" vary somewhat. The following comments, however, are offered as general statements which should be considered as negative features of forming bonded joints with organic polymeric adhesives.

SHELF LIFE LIMITATIONS

Particularly in the case of preformulated thermosetting adhesives, shelf life is limited; in fact, many such systems require refrigeration. Generally, other classes of adhesives are stable in an ambient storage condition. The loss of solvent from solution or the loss of water from latexes should be prevented. Freezing will seriously detract from the stability of a latex dispersion.

Most thermoplastic or hot melt systems have very long or even unlimited shelf life. Most pressure-sensitive adhesives also have a very long shelf life; the elastomeric bases for these adhesive types, however, are subject to oxidative degradation.

WORKING LIFE OR POT LIFE LIMITATIONS

Most two part or multi-component adhesives are of the reactive thermosetting type. Upon mixing, polymerization begins, viscosity starts to increase and working time is therefore limited. Depending on the rate of polymerization, the working life may be as short as a minute or two or as long as several hours.

Because thermosetting polymers react in an exothermic manner, batch size will greatly influence the working life. Heat loss is much greater with small batches, and a reduced temperature build-up will extend the working life.

Large batches of highly reactive systems should be avoided; their exothermic reactions can be hazardous.

Solvent types and latexes generally have long working lfe, although the loss of volatiles may increase the viscosity and skinning will usually occur in a few hours. Most thermoplastics and hot melts have very extended pot lives. Generally, pressure-sensitive types also have long pot lives, although some are in solution and this may restrict working time.

CLEAN SURFACES

Probably the most common reason for unsuccessful adhesively bonded joints is inadequate concern for the preparation of clean, uncontaminated surfaces. In many cases, solvent wiping is carried out with contaminated solvents, or the substrate is touched with fingers resulting in oily contamination of the surface. Equal care should be taken to avoid contamination of the adhesive.

Various interactions occurring at the interface between the adhesive and substrate depend upon an intimate contact between the two. Any contamination of the substrate surface prior to bonding will detract from the adhesive forces operating to form the bond. Dirt, dust, grease or moisture are the usual culprits. Processing steps must be taken to remove such contaminants from the substrate surface.

Some materials, such as aluminum, require special surface oxidative etches in order to obtain oxide coatings which result in the optimum performance of adhesive bonds.

ENVIRONMENTAL LIMITATIONS

Organic polymeric materials have several environmental limitations, a most important one being upper service temperature. Organic adhesives are temperature limited. Oxidative degradation at elevated temperatures results in a loss of thermal plasticity and structural integrity. In some elastomeric-based and thermoplastic-based adhesives, the upper service temperature may be so low that a summer day presents problems. Other thermosetting adhesives, such as some epoxies, can maintain structural integrity at temperatures as high as 350° F. In newer adhesives, such as the polyimides, temperature capability may be as high as 600° F.

Similarly, some adhesive formulations become so brittle at low temperatures that they cannot be considered reliable. A number of adhesive types are available, however, that do offer low-temperature integrity, some even extending down to cryogenic temperatures.

Many adhesive manufacturers provide an upper service temperature which will result in initial strength. Under static load, however, the adhesive will creep and eventually fail at that temperature. Generally, thermosetting adhesives are more resistant to creep than are thermoplastic.

Organic polymeric materials are also subject to attack by chemical agents, ozone and solvents. Even exposure to water detracts somewhat from maximum performance of the adhesive because of plasticization of the polymer and interference with the adhesive forces at the interface.

In many applications, flammability of the adhesive must be considered. Some adhesives are particularly flammable in the uncured form because of formulation with volatile, highly flammable solvents.

Proper selection of an adhesive type by considering the anticipated environment can resolve many of the above disadvantages. No one adhesive is the optimum answer for all applications. Each adhesive has its own profile of chemical and physical behavior determined to a large extent by the performance profile of the principal polymeric material upon which the adhesive is based. When no performance data is supplied by a manufacturer, a potential user can collect some information by determining the generic base of the adhesive and referring to chemical resistance charts of polymeric materials. Such charts can be found in the "desk-top data bank®" books, **Plastics** and **Elastomers.**

PROCESSING LIMITATIONS

Adhesive types which contain volatile solvents or condensation volatiles cannot be used effectively with nonporous substrates unless the glue lines are very narrow. The problem is the trapped volatile material, which either plasticizes the glue line or bubbles to form voids in it. In some solvent types, the solvent can be removed (or mostly removed) prior to bond closure. In some adhesives, such as phenolic-based systems, a fabric carrier may assist in providing a path for venting volatiles.

Because of the above considerations, there has been an effort to utilize polymer systems which react by an addition mechanism and produce no volatile products of the polymerization reaction. The most common addition type is the epoxy resin.

In most thermosetting adhesives, a negative change in volume occurs when the polymerization takes place. This shrinkage can introduce voids, and consequently many adhesives are formulated with solid fillers to reduce this effect. In addition, these solid fillers serve to modify the flow characteristics of the uncured adhesive in the glue line.

In heat-cured adhesives, the thermal profile is a factor in achieving reproducible results. A rapid rise in temperature may not allow sufficient resin advancement to control flow; this results in a watery adhesive that can produce a "starved" glue line. Conversely, too slow a heating rate can result in advancement before any reduction in viscosity is realized, and poor substrate wetting can become a problem.

PEEL STRENGTH

The amount of peel load (or torque) per specified width of a bond line, required to continuously propagate a bond failure substrates, is measured in pounds per lineal inch (see T-Peel, ASTM D-1876) or in-lbs per 3 inch limbing drum peel, MIL A-25463). The peel value of a given adhesive, is not an intrinsic property dependent on a complete spectrum of factors including adhesive and adhesion variables. The peel in test configuration yields a relative comparison between structural adhesives of similar type or peel implies that the adhesive bonds will be more difficult to delaminate under service conditions at exposed edges or adjacent to internal voids.

Careful examination of the failed specimens can be used to determine the mode of failure such as cohesive failure within the adhesive itself or adhesive failure between the adhesive layer and the metal substrate or the metal primer.

Cohesive peel failure means that the adhesive composition is weaker than its bond to the substrate. Apparent cohesive failure is often promoted in film adhesives by the use of a supporting carrier. These fibrous carriers when shredded during the peel process, redistribute the peeling load and this results in higher peel strength. The peeling phenomena in bonded honeycomb panels is even more complex because of the fillet formed by the adhesive at the core to adhesive juncture. The amount, shape and density of this fillet are functions of the bonding process including heatup rate and gravity (top and bottom of the sandwich). These factors give added complexity to the interpretation of the peel torque value. Adhesion peel failures often suggest problems with the cleaning, surface treatment or adhesive-/substrate incompatibility. This is particularly true when the peel failures occur at low values.

Very tough adhesives often fail adhesively, albeit at high values. Once an adhesive mode failure begins, it tends to propagate in the same mode.

The peel value for an adhesive has no engineering design allowable. In other words, it is not used as a design criterion, but because of a vague relationship between a high peel value and increased adhesive toughness, there is a bias towards selecting adhesives with higher peel values for any application. Peel tests are used mainly for product-process control. The peel test results for a given adhesive, bonded in a well defined process and tested in one specimen configuration, are treated in a statistical manner. Finding the cause of a poor result or trend is often a formidable task and requires cooperation among those involved in adhesive raw materials, adhesive manufacture and total bonding process.

C. JOINT DESIGN AND FAILING LOADS

(Ken Berg)

The structural reliability of bonded joints is an important consideration in their use on any system. One of the most significant factors complicating the design of bonded joints is the fact that the stress distribution in the joint is not uniform. In addition a large number of variables affect this stress distribution. Even in a simple lap joint as shown in Figure 1, the number of variables affecting the stress distribution is large. The following variables are involved in lap joint design:

1. Adhesive Properties
   - a) Elongation
   - b) Strength
   - c) Modulus
2. Adhesive Thickness
3. The Length of the Bonded Joint
4. The Properties of the Adherends
   - a) Yield Strength
   - b) Thickness
   - c) Modulus

For other joints, such as a double lap joint, Figure 2, a scarf joint, Figure 3, a stepped lap joint, Figure 4, there are additional variables to be considered. Each variable in the joint contributes to its stress characteristics and is therefore an important consideration in the joint design.

Joint Design Strength

The most important single engineering design consideration to be understood by a joint designer is that the shear stresses in a bonded joint are **never** uniform. The use of an average shear stress, i.e. joint load divided by bond area, therefore always results in stresses which are too low. Only in cases where a near uniform stress occurs does the average stress approach the maximum stress. Failure in the bond always occurs at maximum stress. An understanding of the concept of maximum stress in a joint versus average stress is thus of primary importance in the design of bonded joints.

EFFECT OF ADHESIVE PROPERTIES

The simplest example of the maximum-stress concept can be demonstrated by the stress distribution in a simple single shear lap joint, Figure 5. The shear stress distribution in Figure 5 (a) is the elastic (linear) stress distribution and represents the significant difference that exists between the maximum shear stress, T_{max}, and the average shear stress, T_{avg}. The distribution shown on Figure 5 (a) is more representative of an adhesive that is brittle, with a stress/strain curve as shown on Figure 5 (b).

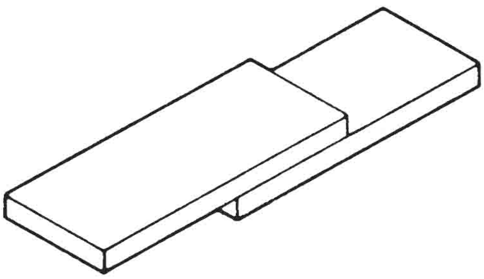


Figure 1 Simple Single Shear Lap Joint

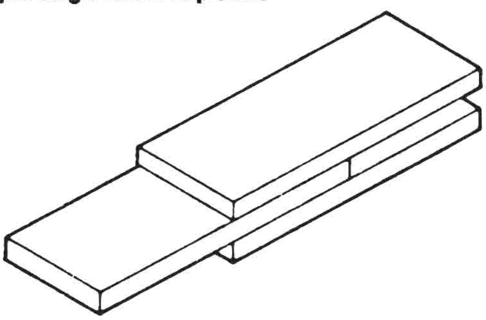


Figure 2 Simple Double Shear Lap Joint

Figure 3 Scarf Joint

Figure 4 Stepped Lap Joint

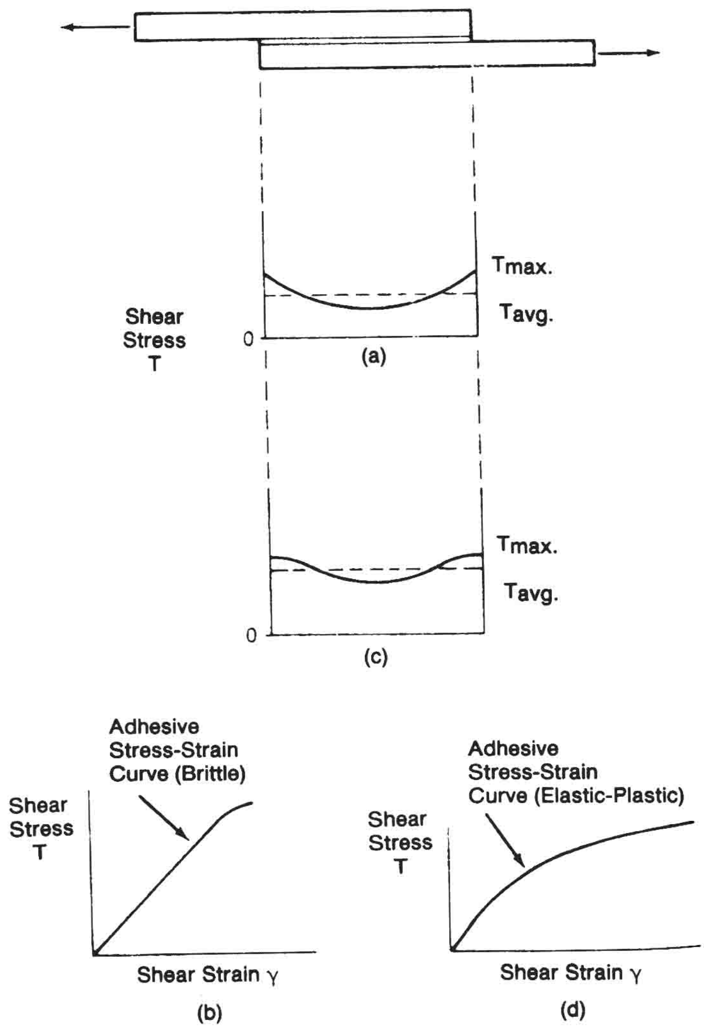


Figure 5 Shear Stress Distribution in Lap Joint