AdTech
European Harmonized Training for Adhesive Bonding Technology

EUROPEAN ADHESIVE ENGINEER

MODULE 7.1

SELECTION TABLES AND PERFORMANCE SPECIFICATIONS

ERASMUS + REFERENCE 2015 -I- PT 01- KA202 - 012915

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7.1 Selection Tables and Performance Specifications

Objectives

✓ Select appropriate adhesive for a specific application with the lowest risk possible by the use of selection tables and performance specifications

✓Know how to redesign a joint in order to guarantee the satisfaction of the adhesive demands and reduce its performance specifications

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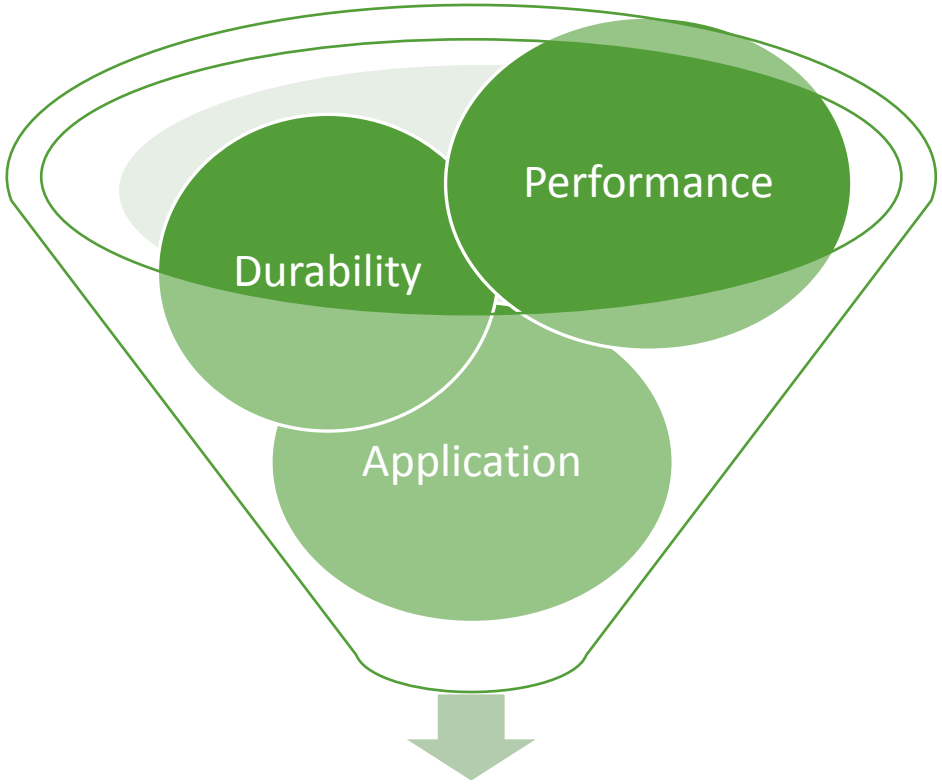
Adhesive Selection Considerations [2]



Suitable Adhesive [1]

- **Performance:**
  - Adhesion ↔ Substrate
  - Applied loading
  - Joint design
  - Mechanical Properties
- **Durability:**
  - Environmental Resistance
  - Chemical Resistance
  - Fatigue
- **Application/Process**
  - Form/Apllication
  - Viscosity/sag
  - Cure
- **Costs**
- **Health and safety**

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Adhesive Selection Considerations [3]

- **Before choosing:**
  - Acquire information from data sheets and/or contact the manufacturer
  - Read the technical data sheet
  - Check the shelf-life

- **After choosing:**
  - Ensure adhesives are stored correctly
  - Acclimatise:
    - Adhesives
    - Auxiliary materials
    - Substrates
  - Clean the adhesive bounding
  - Heed the lower and upper T limits for processing the adhesive → < 5 ºC ✖
  - Only remove the positioning device <u>after</u> reaching <u>hand strength</u>

Types of Adhesives [4]

http://i.vimeocdn.com/video/544891289_1280x720.jpg

- **Types of adhesives**
  - Chemically curing adhesives
    - Polyaddition adhesives
    - Polycondensation adhesives
    - Polymerisation adhesives
  - Physical hardening adhesives
    - Adhesive which harden on cooling
    - Adhesives which harden on drying
    - Gel-forming adhesives
  - Materials precoated with adhesive
    - Pressure activated adhesives
    - Heat activated adhesives
    - Moisture activated adhesives
  - Adhesives with a dual curing/hardening mechanism

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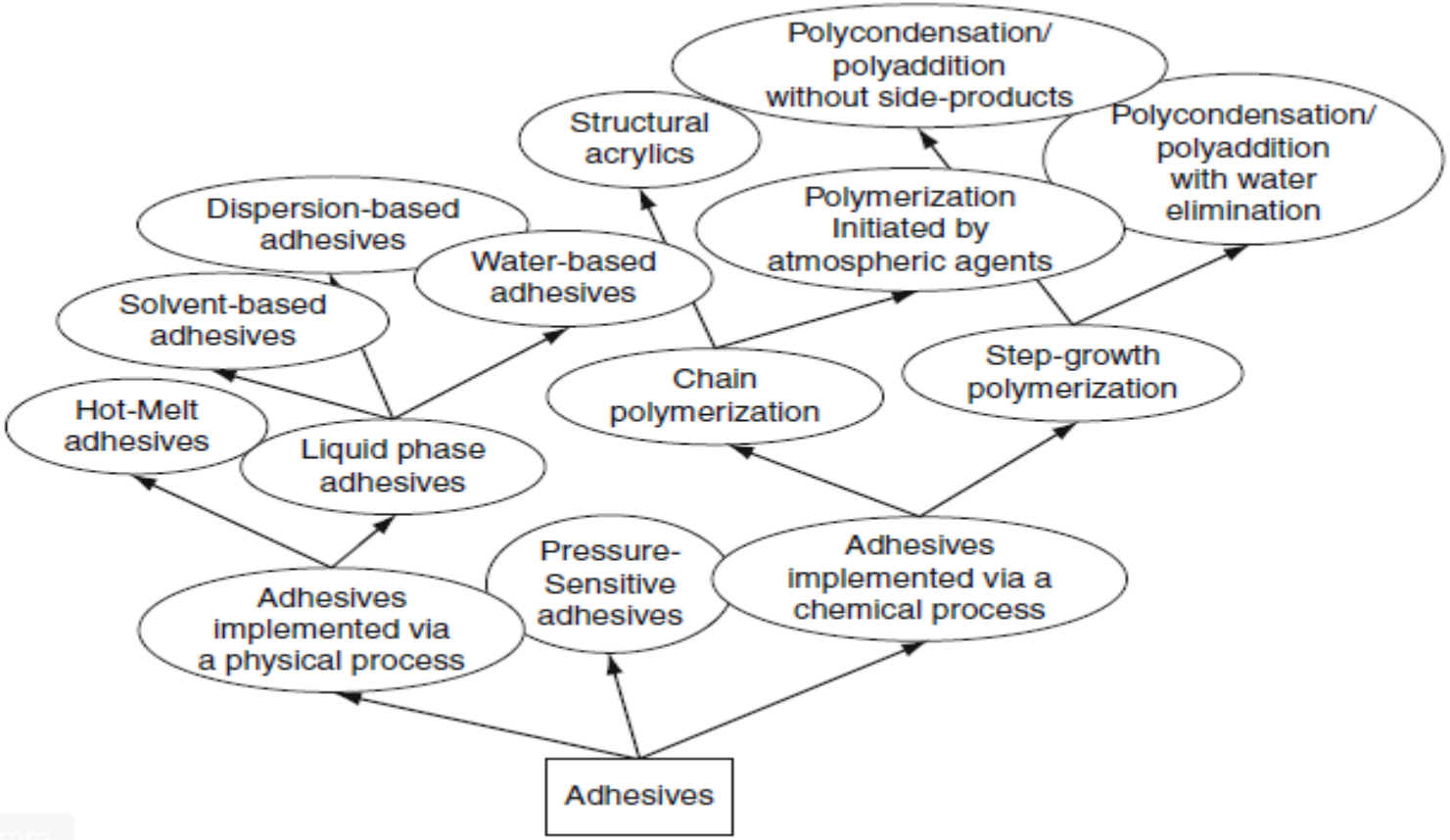
Types of Adhesives

Adhesive "zoology"



A. Ö. R. D. A. Lucas F M da Silva, Ed., Handbook of Adhesion Technology, Springer, 2011, p. 319

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Chemically curing adhesives [4]

- **Polyaddition adhesives**
  - Epoxides
  - Polyurethanes
  - Hot curing natural rubbers
- **Polycondensation adhesives**
  - Silicones
  - Silane-modified adhesives
  - Phenol-formaldehyde resins
  - Polyimides
  - Polysulfides
- **Polymerisation adhesives**
  - Cyanoacrylates
  - MMA
  - Anaerobically curing adhesives
  - Radiation curing adhesives
  - Light activated adhesives
  - Unsaturated polyesters

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Physical hardening adhesives [4]

- **Adhesives which harden on cooling**
  - Hotmelts
- **Adhesives which harden on drying**
  - Solvent based adhesives
  - Dispersion adhesives
  - Colloidal systems
  - Contact adhesives
- **Gel-forming adhesives**
  - Plastisols

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Technical Performance Specifications

- Written requirements that describe the functional performance criteria required for a particular equipment, material, or product. [13]

- May include: [14]
  - Performance to be achieved
  - Operating environment, if any specific environment standards
  - Required safety levels
  - Required quality levels

- They state:[15]
  - the purpose of the project
  - the area of use
  - the development stages and composition of design documentation
  - completion deadlines
  - special requirements resulting from specific features of the project itself or the project's operating conditions

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Technical Performance Specifications [14]

- Buyer informs what the product is expected to do
- How a product is made? ✗ → How (well) it performs? ✓
- Supplier should offer a product that will meet the performance-requirements
- The specification defines the performance to be achieved
  ⇒ Does not prescribe how to achieve!

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Steps to choose the right adhesive [5]

1-Are there any certifications or qualifications the adhesive must meet?

2-Select the correct technology for the application

3-What are the application specific requirements?

4-What are the process requirements?

5-TEST the adhesive

Adhesive Health Risk?

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Steps to choose the right adhesive [5]

STEP 2: Select the correct technology for the application

- **Anaerobics:** cure when in contact with metal without contact with air
  - Include thread locker adhesives, used to lock bolts into nuts
- **Cyanoacrylates:** cure through reaction with moisture.
  - works best with rubber or as a plastics adhesive on small components
  - bond most substrates well but have poor durability on glass.
- **Toughened Acrylucs:** come in 1 and 2 part systems and work well on a wide variety of surfaces.
  - Versatile, working with minimal surface preparation.
- **Epoxies:** Available in 1 and 2 part: structural strength on metals but do not excel on plastics.
  - Single part epoxies require ovens to cure them
  - 2 part epoxy may require +f time to cure.

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Steps to choose the right adhesive [5]

STEP 2: Select the correct technology for the application

- **Polyurethanes:** ↑resistance to ↓T and excellent for bonding GRP, or glass fibre reinforced plastics
  - Impact resistant and cure quickly with the help of special tools
- **Silicones:** aren't strong but are quite flexible and resistant to ↑T
  - 2-part silicone products tend to work + effectively than the 1-part products. These are a popular choice for shower and bathtub repairs.
- **Phenolic:** require heat and pressure for the curing process
  - Excellent in bonding metals, or bonding metals to wood
- **Polyimides:** Available in liquid and film form but tend to be + expensive and tricky to handle efficiently.
  - ↑ durability under extreme T

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Steps to choose the right adhesive [5]

STEP 2: Select the correct technology for the application

- **Hot Melts:** aren't very strong but work well as an instant adhesive for fast production on components that won't have much pressure placed on them.
- **Plastisols:** require heat in order to cure and generally produce strong, durable joints..
- **PVA :** excellent solution for porous materials, including wood and paper.
- **Pressure Sensitive Adhesives:** durable in various environments and excellent for labeling and on adhesive tapes but aren't much of an option for industrial adhesives purposes

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Steps to choose the right adhesive

STEP 2: Select the correct technology for the application

Performance considerations	Cyanoacrylates	Epoxies	Hot melts	Light Cure
Advantages	Wide range of bonding applications Ease of use	Wide range of formulations	Versatile Fast Large gap filling	Rapid cure adhesion to Plastics Bond on demand
Disadvantages	Low polar solvent resistance	Mixing required	Limited heat resistance	Light cure required

The Adhesive Sourcebook, vol. 19, LOCITE Products for Design, Assembly, Manufacturing and Maintenance, 2015.

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Steps to choose the right adhesive

STEP 2: Select the correct technology for the application

Performance considerations	Silicones	Elastomers	Urethanes	2-Part Acrylics	2-Step acrylics
Advantages	Excellent T resistance	Flexible Paintable Bonder/sealant	Excellent Toughness/ flexibility	Good impact resistance/ flexibility	Good impact resistance/ no-mix
Disadvantages	↓ adhesion resistance	↑T resistance	Sensitive to moisture	Mixing required	Primer required

The Adhesive Sourcebook, vol. 19, LOCITE Products for Design, Assembly, Manufacturing and Maintenance, 2015.

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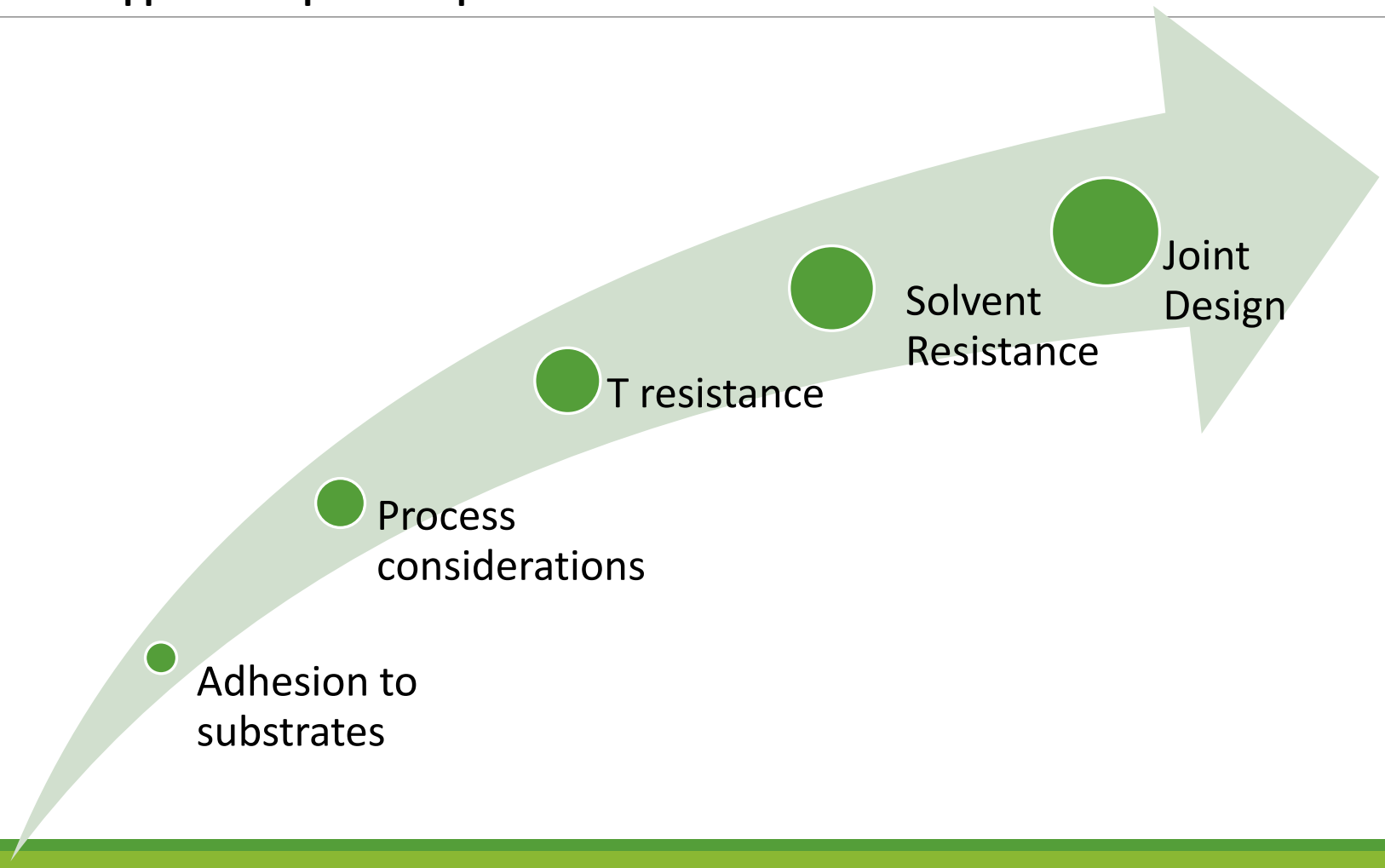
Steps to choose the right adhesive [5]

STEP 3: What are the application specific requirements?



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Steps to choose the right adhesive

STEP 3: What are the application specific requirements?

Adhesion to Substrates

	Cyanoacrylates	Epoxies	Hot melts	Light Cure
Metals	Very Good	Excellent	Good	Good
Plastics	Excellent	Fair	Very Good	Excellent
Glass	Poor	Excellent	Good	Excellent
Rubber	Very Good	Fair	Fair	Fair
Wood	Good	Very Good	Excellent	Poor
OVERLAPPING SHEAR STRENGTH	High	High	Low	High
PEEL STRENGTH	Low	Medium	Medium	Medium
TENSILE STRENGTH	High	High	Low	High
FLEXIBILITY	Low	Low	High	Medium
HARDNESS	Rigid	Rigid	Semisoft	Semirigid

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Steps to choose the right adhesive

STEP 3: What are the application specific requirements?

Adhesion to Substrates

	Silicones	Elastomers	Urethanes	2-Part Acrylics	2-Step acrylics
Metals	Good	Very Good	Good	Excellent	Excellent
Plastics	Fair	Good	Very Good	Excellent	Fair
Glass	Very Good	Good	Good	Good	Excellent
Rubber	Good	Poor	Good	Poor	Poor
Wood	Fair	Very Good	Fair	Good	Good
OVERLAPPING SHEAR STRENGTH	Low	Medium	Medium	High	High
PEEL STRENGTH	Medium	Medium	Medium	High	Medium
TENSILE STRENGTH	Medium	Medium	Medium	High	High
FLEXIBILITY	High	High	High	Medium	Medium
HARDNESS	Soft	Soft	Soft	Semirigid	Semirigid

The Adhesive Sourcebook, vol. 19, LOCITE Products for Design, Assembly, Manufacturing and Maintenance, 2015.

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Steps to choose the right adhesive

STEP 3: What are the application specific requirements?

Process

Fixture time	Average	Fastest	Full Cure Time
Cyanoacrylates	30 s	<5 s	24 h
Epoxies	20 min	3-5 min	12-24 h
Hot melts	70 s	20 s	1 h but Urethane Hot Melts require 24 hours for full cure.
Light Cure	30 s	<5 s	30-60 s
Silicones	25 min	2 min	1-7 days
Elastomers	25 min	10 min	1-7 days
Urethanes	25 min	5 min	24 h
2-Part Acrylics	20 min	3-5 min	24 h
2-Step acrylics	5 min	30 s	24 h

The Adhesive Sourcebook, vol. 19, LOCITE Products for Design, Assembly, Manufacturing and Maintenance, 2015.

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Steps to choose the right adhesive

Process

STEP 3: What are the application specific requirements?

Gap fill	Ideal (mm)	Max. (mm)	Dispensing/Mixing equipment required	Light Cure Versions available
Cyanoacrylates	0,0254-0,254	5,08	NO	YES
Epoxies	0,1016-0,1524	3,175	YES	YES
Hot melts	0,0508-0,127	6,096	YES	NO
Light Cure	0,0508-0,254	6,35	NO	YES
Silicones	0,0254-0,1524	6,35	NO	YES
Elastomers	0,0254-0,1524	6,096	NO	NO
Urethanes	0,1016-0,1524	3,175	YES	NO
2-Part Acrylics	0,254-1,016	12,7	YES	NO
2-Step acrylics	0,0508-0,1016	1,016	NO	YES

The Adhesive Sourcebook, vol. 19, LOCITE Products for Design, Assembly, Manufacturing and Maintenance, 2015.

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Steps to choose the right adhesive

STEP 3: What are the application specific requirements?

T resistance

T resistance	Typical for the category (ºC)	Highest rated product (ºC)
Cyanoacrylates	-54 to 99	121
Epoxies	-54 to 82	204
Hot melts	-54 to 121	166
Light Cure	-54 to 149	180
Silicones	-54 to 204	385
Elastomers	-54 to 93	93
Urethanes	-54 to 121	149
2-Part Acrylics	-54 to 121	121
2-Step acrylics	-54 to 149	204

The Adhesive Sourcebook, vol. 19, LOCITE Products for Design, Assembly, Manufacturing and Maintenance, 2015.

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Steps to choose the right adhesive

STEP 3: What are the application specific requirements?

Solvent Resistance

T resistance	Polar Solvents	Nonpolar Solvents
Cyanoacrylates	Poor	Good
Epoxies	Very Good	Excellent
Hot melts	Good	Good
Light Cure	Good	Very Good
Silicones	Good	Poor to Fair
Elastomers	Good	Poor
Urethanes	Good	Good
2-Part Acrylics	Good	Very Good
2-Step acrylics	Good	Very Good

The Adhesive Sourcebook, vol. 19, LOCITE Products for Design, Assembly, Manufacturing and Maintenance, 2015.

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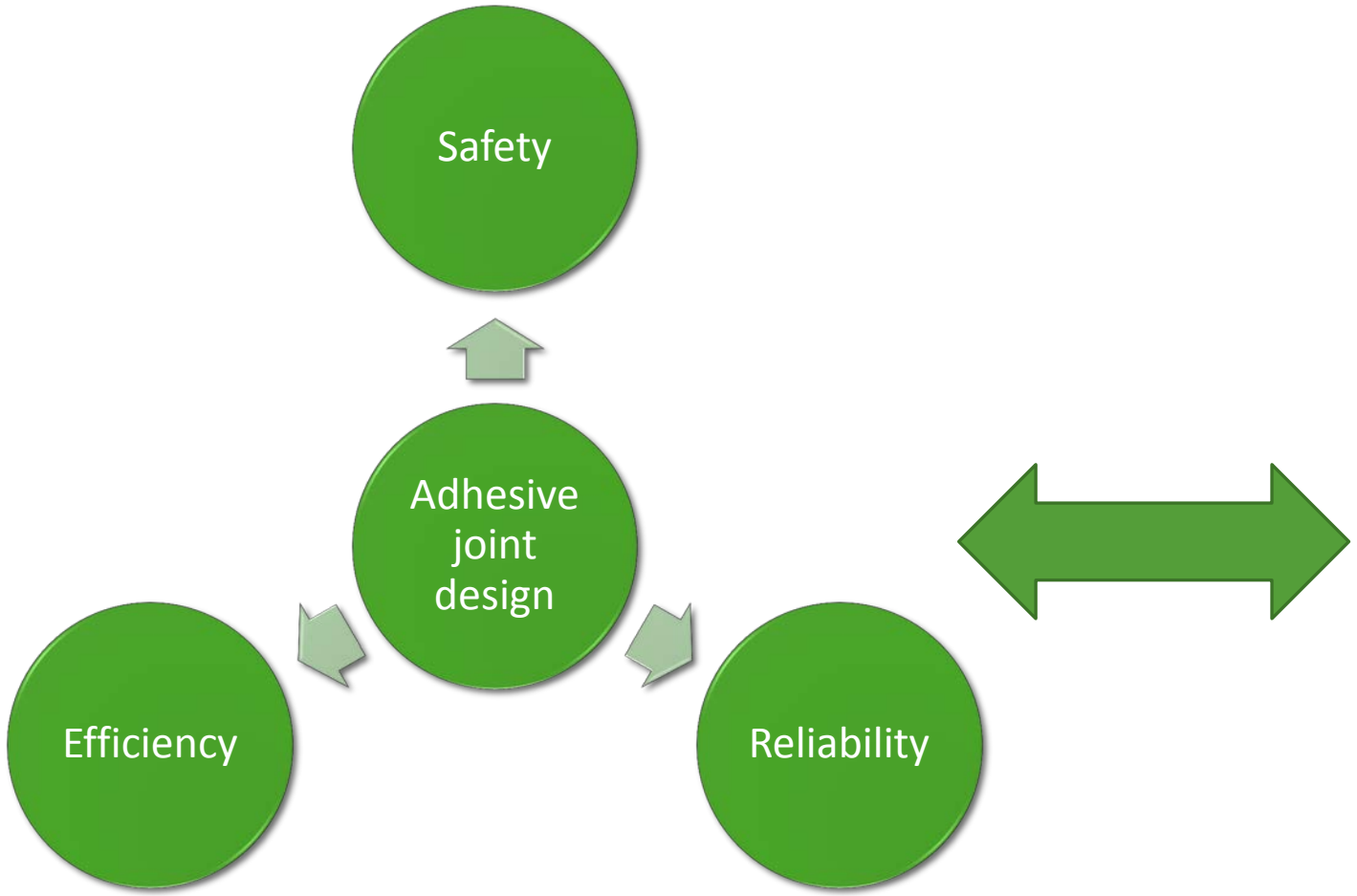
Steps to choose the right adhesive [6]

STEP 3: What are the application specific requirements?

Joint Design



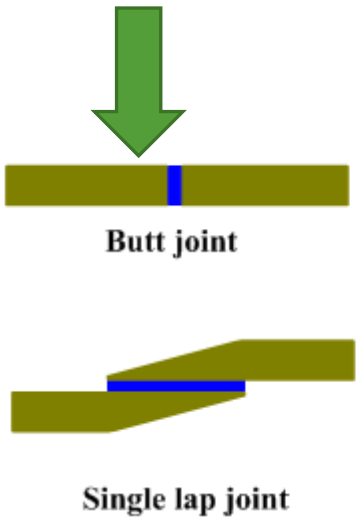
Failure **should not** occur during the life of a component/structure of interest

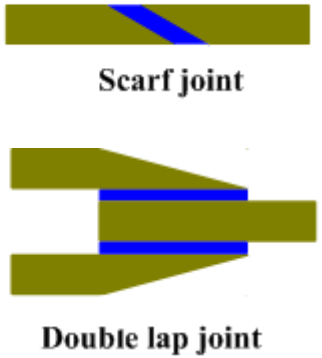
Steps to choose the right adhesive

STEP 3: What are the application specific requirements?

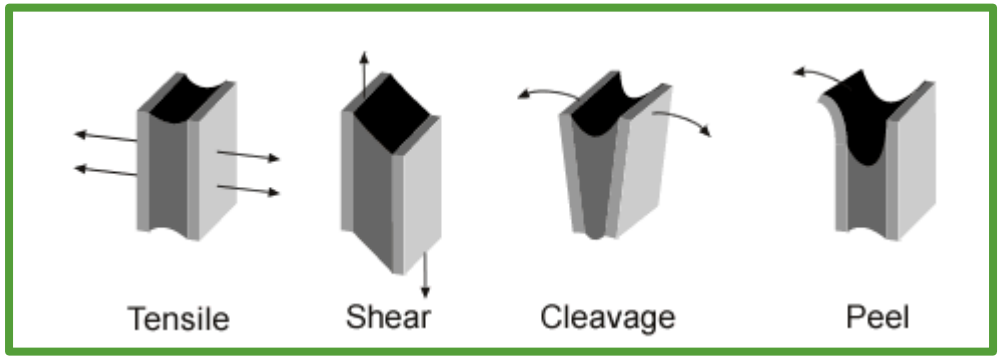
Joint Design

Joint Type → Materials → Clearance → Surface finish → Engagement ratio → Load → **Joint design factors**





T-Joint



http://www.substech.com

A. Ö. R. D. A. Lucas F M da Silva, Ed., Handbook of Adhesion Technology, Springer, 2011, p. 598

http://www.adhesivestoolkit.com/Toolkits/DesignGuidance/JointTypes.xtp

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Steps to choose the right adhesive

STEP 3: What are the application specific requirements?

Joint Design

The choice of joint type will depend on the nature of the structure that is to be created

Joint Strength >>> under shear deformation

Geometry that minimises the tension stresses at the edges of the overlap

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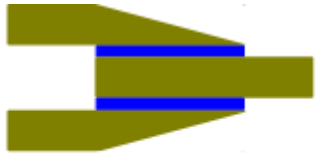
Steps to choose the right adhesive [7], [8]

STEP 3: What are the application specific requirements?

Joint Type

Single lap joint

+	−
Simplest joint geometry	Detrimental peel stresses



Double lap joint

+	−
Reduces peel stresses	Difficult to manufacture

http://www.substech.com

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Steps to choose the right adhesive [7], [8]

STEP 3: What are the application specific requirements?

Joint Type

Scarf joint

Ideal for eliminating peel stresses

- Harder to create
- Not suitable with thin sheet adherents

Butt joint

- Simple joint geometry
- Can be used to transmit torsional loading.

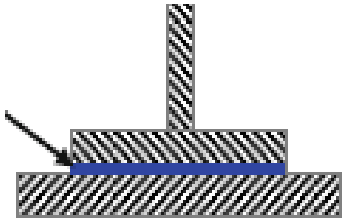
Not suitable for load bearing components (due to its inherent weakness to tension and cleavage forces)

http://www.substech.com

Steps to choose the right adhesive [8]

STEP 3: What are the application specific requirements?

Joint Type



T-Joint

A. Ö. R. D. A. Lucas F M da Silva, Ed., Handbook of Adhesion Technology, Springer, 2011, p. 598

If 2 members require joining at 90º to each other (or some other angle)
⇒ T-joint Should be used

Requires careful design to minimise tensile loading!

Steps to choose the right adhesive [8]

STEP 3: What are the application specific requirements?

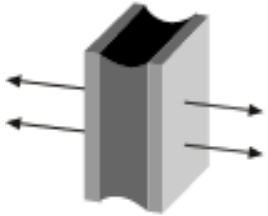
Joint Load

Shear

- **+ desirable**
- Results primarily in shear deformations of the adhesive
- The stresses are less concentrated at the edges of the joint than for the other types of loading ⇒ the adhesive is less susceptible to failure

Cleavage

Peel



Tensile

- ↑ concentrations of shear stress in the adhesive at the edges of the joint
- Loading: difficult to apply uniformly

⇒ higher concentrations of stress on 1 side of the joint.

Result in concentrations of normal tensile stress though the adhesive layer at the edge of the joint ⇒ susceptible to failure.

Steps to choose the right adhesive

STEP 3: What are the application specific requirements?

Joint Design

If the performance specifications are unnecessarily high demanding on adhesives due to the joint design, which exposes the adhesive to extremely high loads

Redesign the joint

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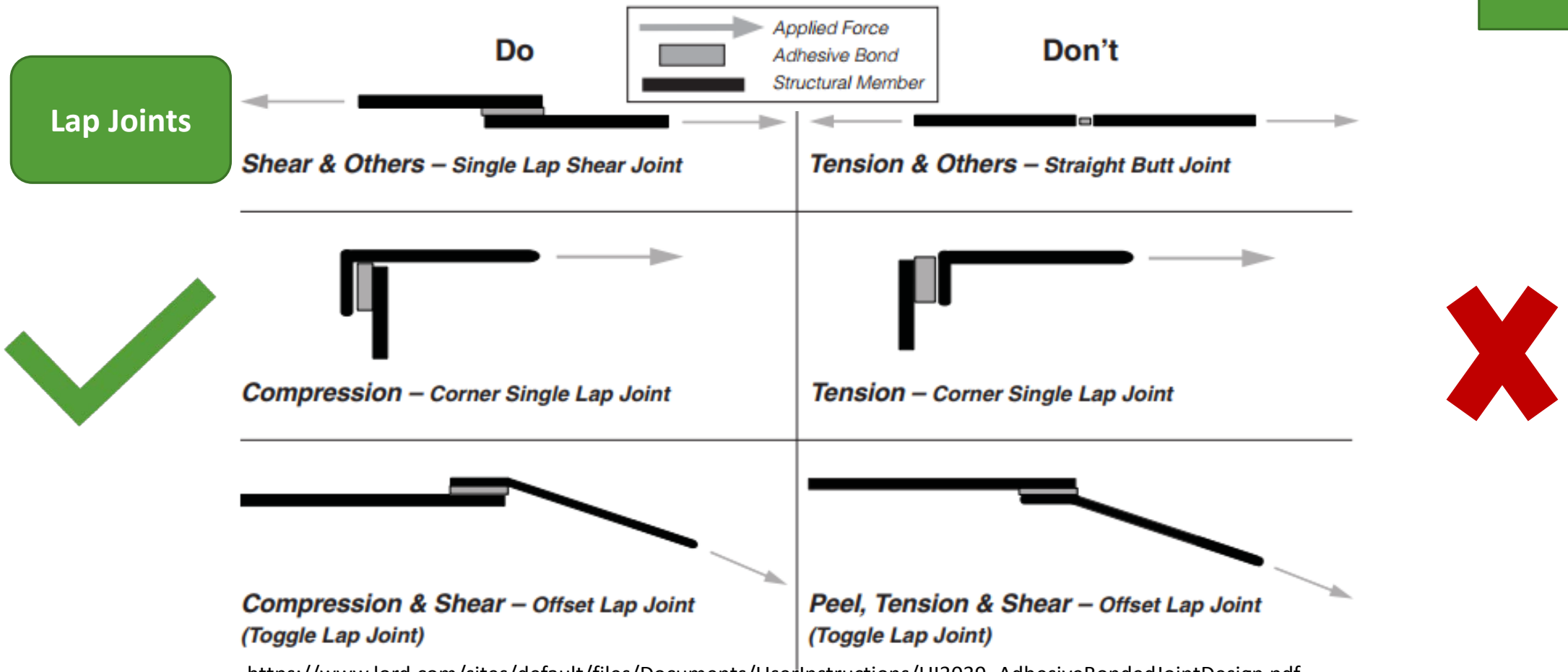
Steps to choose the right adhesive

STEP 3: What are the application specific requirements?

Joint Design

Lap Joints



https://www.lord.com/sites/default/files/Documents/UserInstructions/UI3039_AdhesiveBondedJointDesign.pdf

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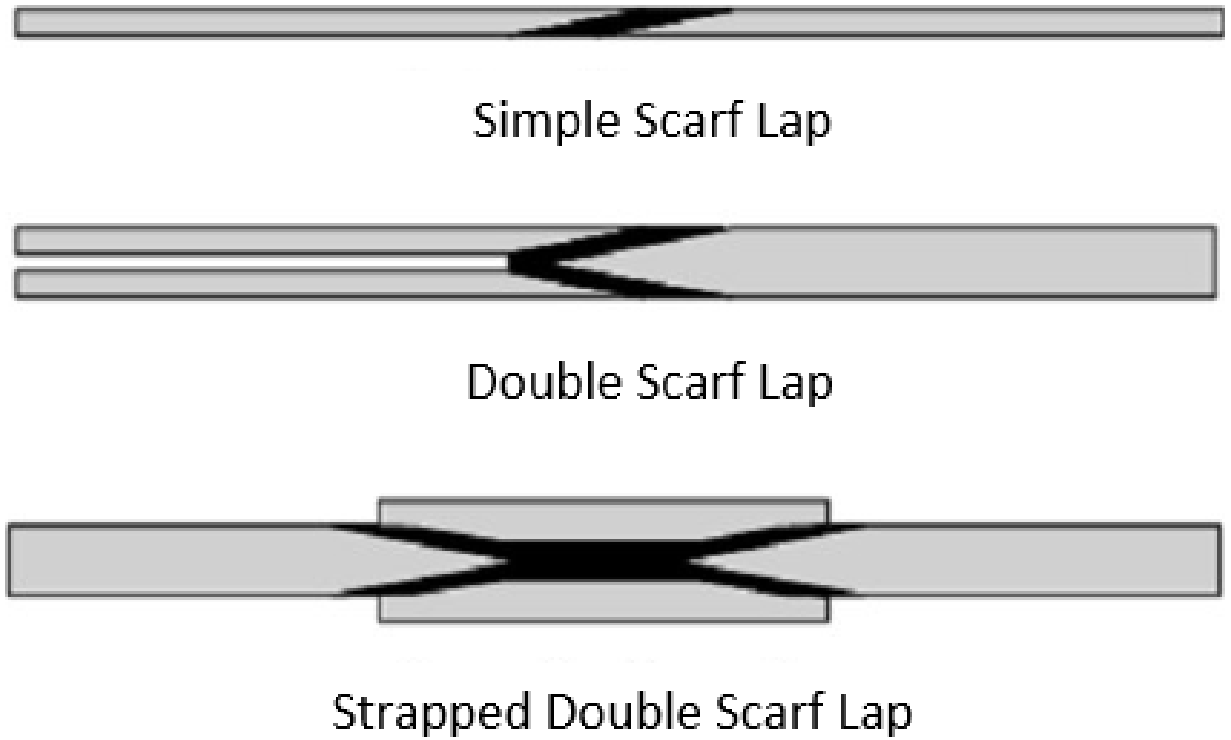
Steps to choose the right adhesive

STEP 3: What are the application specific requirements?

Joint Design

Scarf Joints



- ✓ Eliminates the asymmetry of the lap joints
- ✓ Removes the associated peel stresses, when loaded

X The available bond area is highly dependent on the thickness of the adherends

http://www.adhesivestoolkit.com/Toolkits/DesignGuidance/Scarf.xtp

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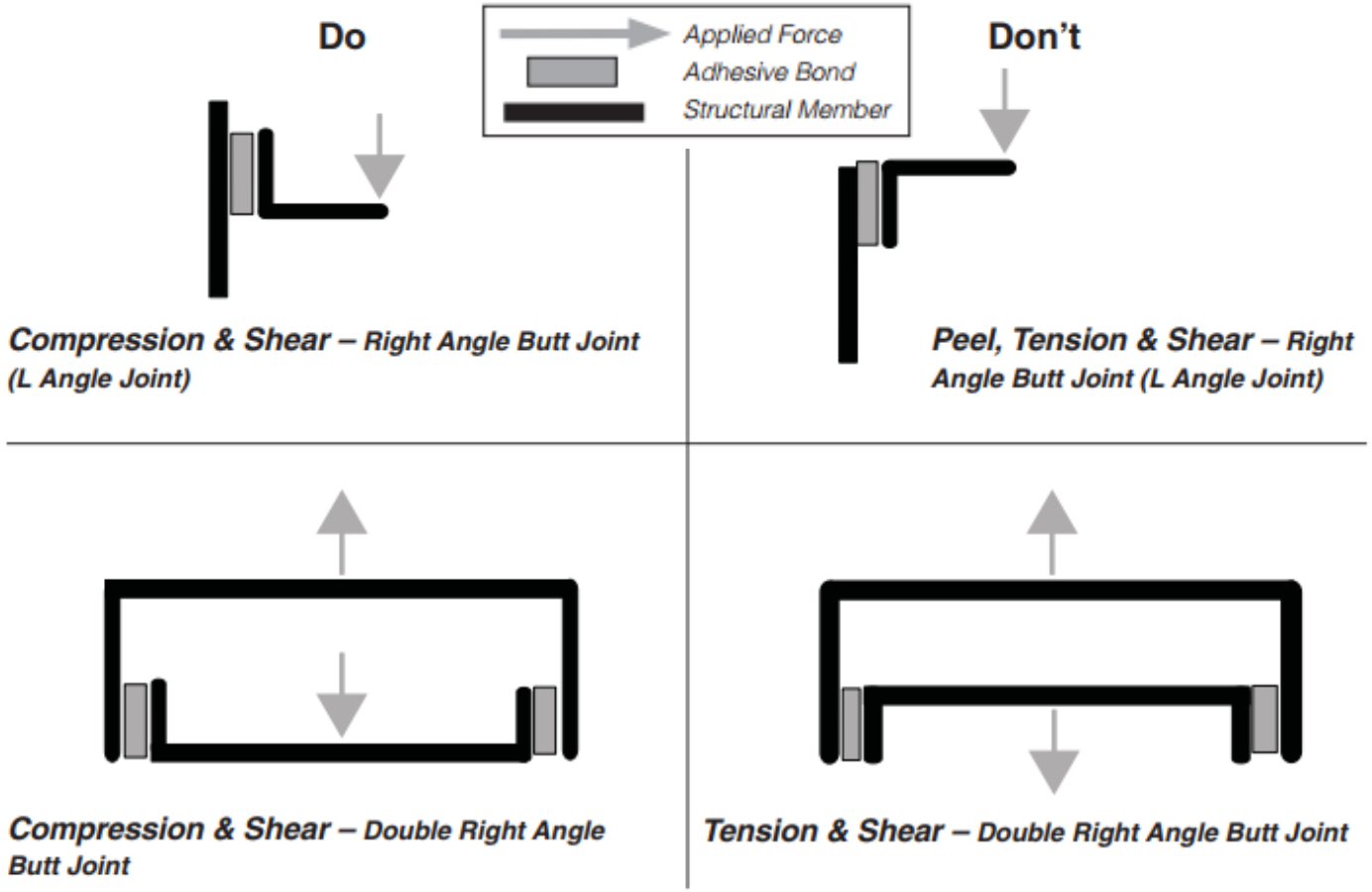
Steps to choose the right adhesive

STEP 3: What are the application specific requirements?

Joint Design

Butt Joints



https://www.lord.com/sites/default/files/Documents/UserInstructions/UI3039_AdhesiveBondedJointDesign.pdf

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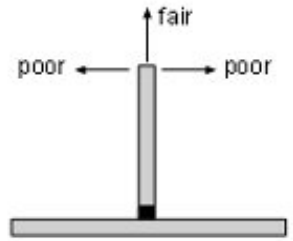
Steps to choose the right adhesive

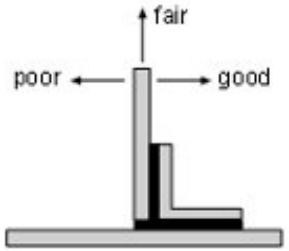
STEP 3: What are the application specific requirements?

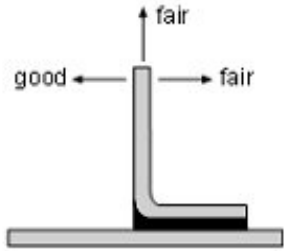
Joint Design

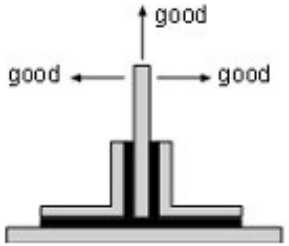
T- Joints

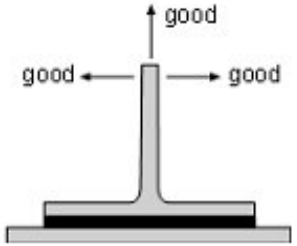


simple T-joint









http://www.adhesivestoolkit.com/Toolkits/DesignGuidance/TJoint.xtp

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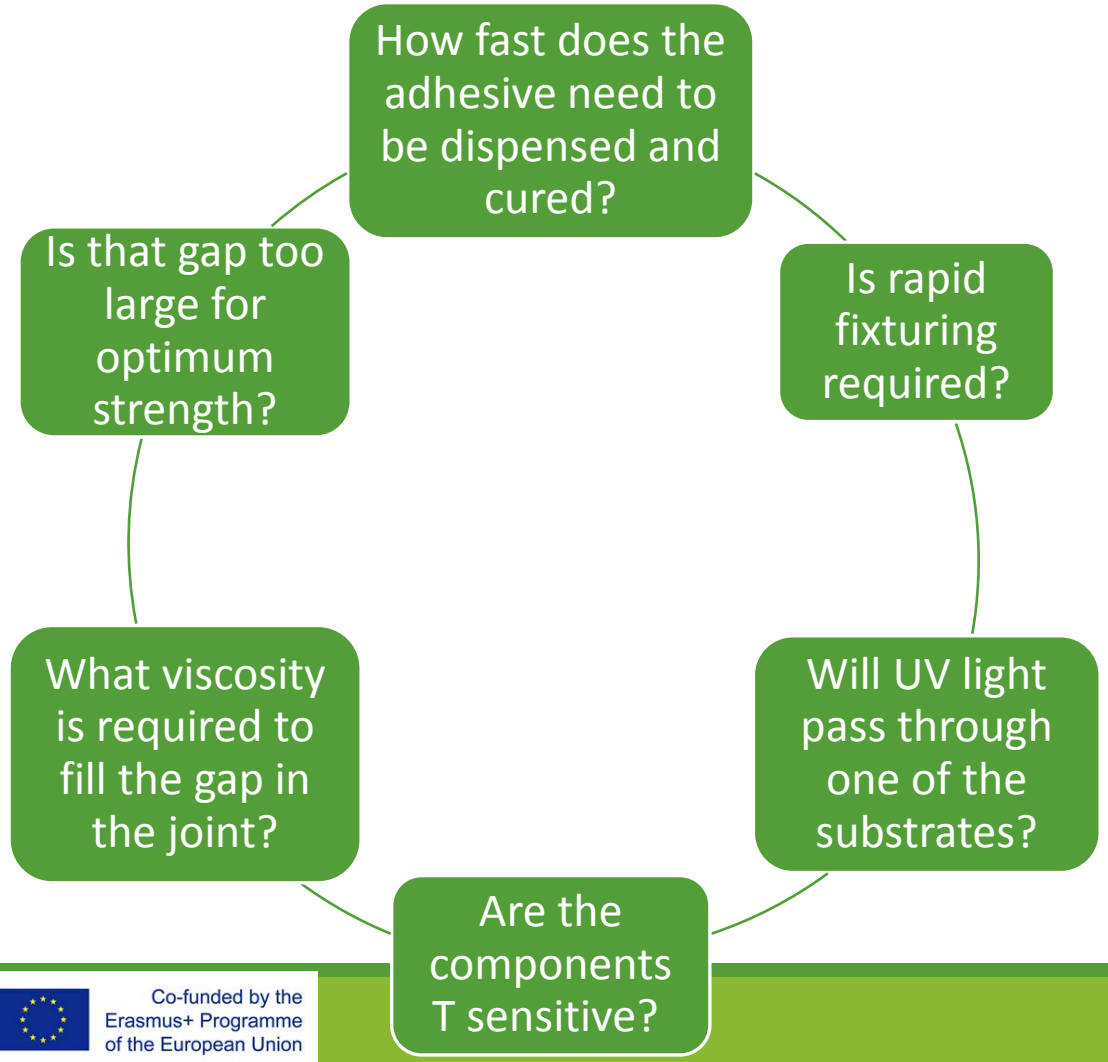
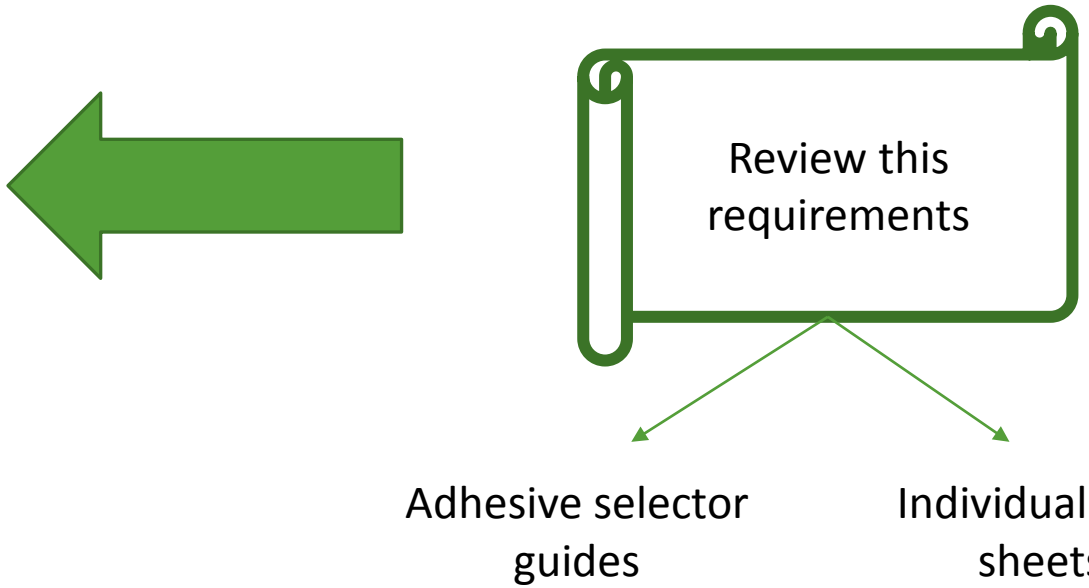
Steps to choose the right adhesive [5]

STEP 4: What are the process requirements?





Steps to choose the right adhesive [5]

STEP 5: TEST

A large nr of variables can affect the bond

The only sure way is to TEST the adhesives in actual conditions

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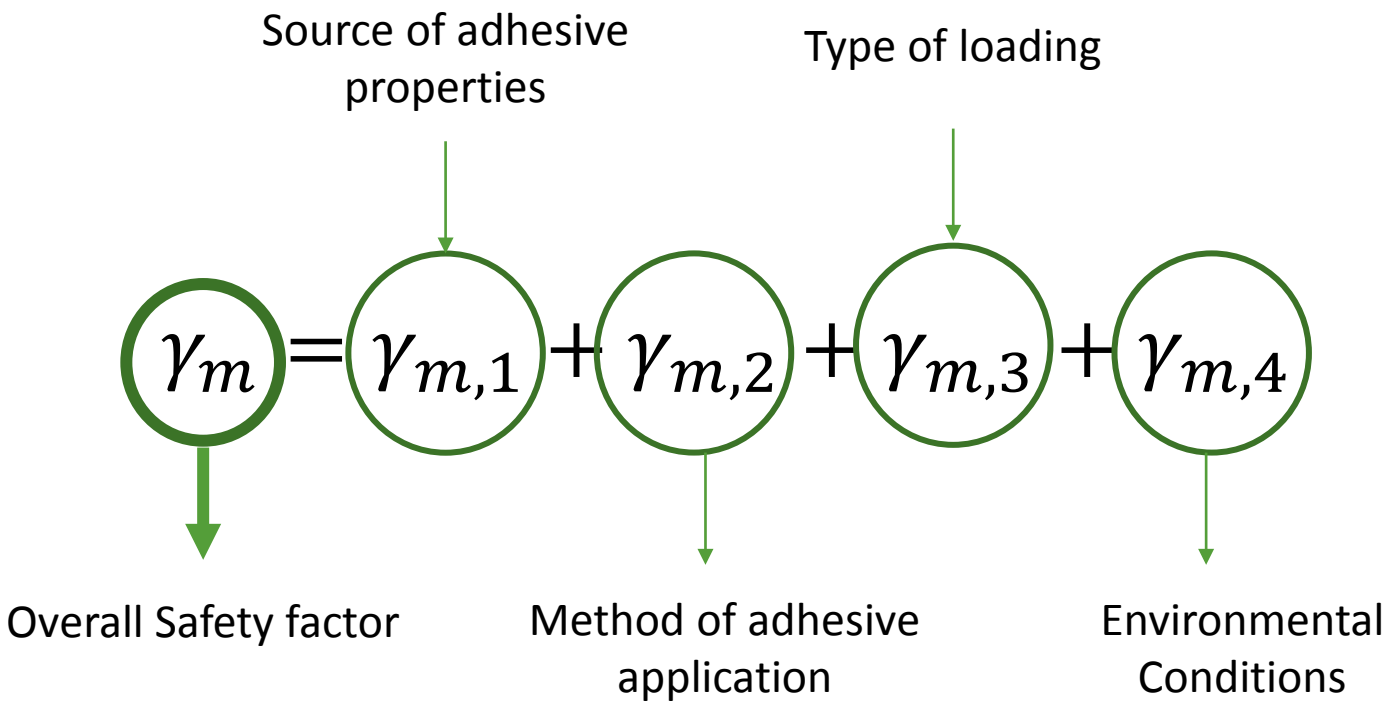
Steps to choose the right adhesive [9]

Adhesive Health Risk?

Safety



Steps to choose the right adhesive [10]

Safety

Adhesive Health Risk?

Hazardous substances used in adhesive bonding work

Adhesives

Substances used during surface treatment

- Primers
- Etching solutions
- Cleaning agents
- Gases
  - Flame or plasma treatment

Substances formed during subsequent processes

- Gases released during spot welding
- Reaction products of subsequent processing steps

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Steps to choose the right adhesive

Safety

Adhesive Health Risk?

Safety guidelines recommended for adhesives and sealants commonly used

	Components	Health Hazard
Physically Hardening Adhesives	Mainly solid polymers and resins that are converted to a liquid form. This can either be carried out by: - Users by means of heating (hot melts) - adhesive manufacturers by dissolving the components in organic solvents or dispersing the components in water. The dry, fully-aired adhesive is generally unreactive and biologically inert	Usually no health hazard. BUT, there is a potential health hazard from auxiliary components, such as organic solvents, that are present in some of these adhesives. These can make up as much as 80% of the weight of the adhesive product.

A. Ö. R. D. A. Lucas F M da Silva, Ed., Handbook of Adhesion Technology, Springer, 2011, p. 1001

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Steps to choose the right adhesive

Adhesive Health Risk?

Safety

	Components	Health Hazard
Hot melts (*)	Polymers and resins and only small amounts of auxiliary materials.	There is virtually never a health hazard. When applying these adhesives manually, there is the **risk of burns** and users must protect themselves against this. During heating, small amounts of auxiliary materials and contaminants can be liberated ⇒ **Ventilation system** is recommended due to the large quantities being used and long working times with the adhesives.

A. Ö. R. D. A. Lucas F M da Silva, Ed., Handbook of Adhesion Technology, Springer, 2011, p. 1001

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Steps to choose the right adhesive

Adhesive Health Risk?

Safety

	Components	Health Hazard
Solvent Containing Adhesives (e.g. Contact adhesives)	Polymers and resins are dissolved in organic solvents	The hazard potential is determined by the nature of the solvent Due to the high volatility of the solvents, exposure by **inhalation of the vapors** is the biggest problem. For most solvents the maximum concentration at the workplace and limiting factors are laid down

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Adhesive Health Risk?

Safety

	Components	Health Hazard
Dispersion Adhesives (e.g. PVA Wood Adhesives)	Organic solvents are replaced by water and suitable polymers are dispersed in the water	No potential health hazards from organic solvents However, water-based adhesives are sensitive to attack by micro-organisms ⇒ dispersion adhesives should contain small amounts of preservatives The potential health hazard is the triggering of **allergic skin reactions** Skin contact is here the exposure issue and should be avoided
Plastisols (*)	When applying these adhesives manually, there is the **risk of burns** and users must protect themselves against this. During heating, small amounts of auxiliary materials and contaminants can be liberated ⇒ **Ventilation system** is recommended due to the large quantities being used and long working times with the adhesives.	

http://www.adhesives.org/adhesives-sealants/adhesives-sealants-overview/health-safety/industrial-consumer-safety

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Steps to choose the right adhesive

Adhesive Health Risk?

Safety

	Components/ Health Hazard
Pressure Sensitive Adhesives	Private users only come into contact with these adhesives in the form of self-adhesive articles such as labels, adhesive tape, etc. ⇒These adhesives represent no hazard to private users in practice. Such articles are manufactured industrially using adhesives in the form of solutions, but mostly using dispersions and melts.

A. Ö. R. D. A. Lucas F M da Silva, Ed., Handbook of Adhesion Technology, Springer, 2011, p. 1001

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Adhesive Health Risk?

Safety

	Components/ Health Hazard
Chemically Curing	The chemically reactive monomers/oligomers and hardeners and crosslinking agents determine the potential health hazard of these products. Once fully cured, the adhesive polymers are in general non-hazardous. Exposure and risk considerations hence only apply for the time period up until the adhesives have fully cured. Chemically curing may be classified into: - Single Component (1-C): Heat Curing, Moisture Curing, Cyanoacrylates, Anaerobic, Radiation Cure, Silicones - Two-Component (2-C): Epoxiens, Urethanes, MMA's, Silicones

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Safety 1-C

Adhesive Health Risk?

	Health Hazard
Heat Curing (e.g. epoxies, phenol-formaldehyde) (*)	When applying these adhesives manually, there is the **risk of burns** and users must protect themselves against this. During heating, small amounts of auxiliary materials and contaminants can be liberated ⇒ **Ventilation system** is recommended due to the large quantities being used and long working times with the adhesives.
Anaerobic	Begin to cure when are confined between substrates of limited dimension ⇒ removing ambient air. Oxygen stabilizes these products, so the elimination of it (as in a joint), along with the presence of a free radical metallic ion the cure begins. Many of these materials contain some amount of mild acids and acrylic monomers so the use of gloves and eye protection is advised. Ventilation is not normally needed; however, in flange sealing, larger amounts are applied so **open areas** are often advised

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Steps to choose the right adhesive

Adhesive Health Risk?

Safety 1-C

	Health Hazard
Moisture Curing (e.g. polyurethanes) **+ 1-C Silicones**	React with water from the surroundings or water on the substrate. When applying these materials, it is suggested to wear gloves, and eye protection. These materials cure over a period of hours or even days but contact with the skin should be minimized as they can cause some skin irritation/dermatitis. Vapors can cause eye irritation and direct contact to the eyes with rubbing may cause some abrasion to them. In limited use, no additional protection is needed; however, an open area is recommended for production use. As with any moisture curing product, increasing the ambient humidity level will decrease cure time.

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Steps to choose the right adhesive

Adhesive Health Risk?

Safety 1-C

	Health Hazard
Cyanoacrylates	React with water from the surroundings or water on the substrate. Potential health hazard: **contact with the eyes** or splashes of adhesive enter the eye then undesired bonding can take place (can gradually be dissolved using a soap solution). Possible irritation caused by the cyanoacrylate monomer, thermal effects and the rapid polymerization reaction have to be taken into consideration. Increasing the humidity prevents irritation of the respiratory tract. When carrying out major bonding tasks, not only is it recommended **to adjust the humidity of the air but also to wear safety glasses and protective gloves.**

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Steps to choose the right adhesive

Adhesive Health Risk?

Safety 1-C

	Health Hazard
Radiation Cure	Method of initiation of the cure. Uses a photoinitiator as one of the raw materials in the adhesive/sealant. Once exposed to the chosen wavelength of energy (UV, Vis and even microwave) the photonitiator will react and cause the initiation of the curing process. In terms of safety, there are 2 concerns: - the adhesive/sealant itself - energy emitting source: Microwave energy must always be shielded. Use of UV light requires eye and skin protection. Many of the radiation curing adhesives utilize high intensity lights which are harmful to look at without eye protection. The same concerns are appropriate when discussing VIS light cure. In this case the concern is the intensity of the light source. Again, use of eye protection is necessary.

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Steps to choose the right adhesive

Safety 2-C

Adhesive Health Risk?

	Health Hazard
Epoxies	Epoxy materials have both a resin and hardener, which require mixing prior to use. These should be done with **gloves and eye protection** as they can cause mild skin and eye irritation. Normally, inhalation is not a concern; however, some people will experience some respiratory tract irritation, so **open areas** are suggested.
MMA's	These materials have a strong, pungent odor, and can cause headaches, nausea, dizziness and respiratory tract irritation. They cure via the mixing of the two parts, so when handling, **gloves and eye protection** are recommended. They are irritating to the skin and eyes. Localized ventilation is suggested for prolonged use. Otherwise, application in an **open area** is suggested.

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Steps to choose the right adhesive

Adhesive Health Risk?

Safety 2-C

	Health Hazard
Silicones	Silicones react with water, which can release either acetic acid or alcohols. The acetic acid can be clearly sensed by the nose before any irritation begins. In general the slowly released amounts are so small that they present no health risk, especially in the case of private users. Old formulations of neutral silicones which release butanone oxime must be labeled, but they are only used nowadays for special applications. It should be noted that these products may also be found as single component products.
2-C Urethanes	When 2-C polyurethane is used, the reaction for curing is the combining of the two parts. The mixed material is similar in safety related concern to the 1-C urethane as described before

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Adhesive Selection [12]

Private Users → ✗ No Legal Requirements but "prevention is better than cure"

Commercial Users →

Adhesive Selection based on:

- Technical Requirements
- Potential health hazard

If 2 adhesives are = suitable:
The 1 providing the lower potential health hazard **must be chosen!**

Adhesive Selection [12]

Commercial Users

If using an adhesive that does represent a potential health hazard is unavoidable for technical reasons

The exposure must be limited by taking suitable measures

Which may include

Automating the process, such that a risk to health is prevented

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