Automotive Structural Joining

2018, Henkel Adhesive Technologies

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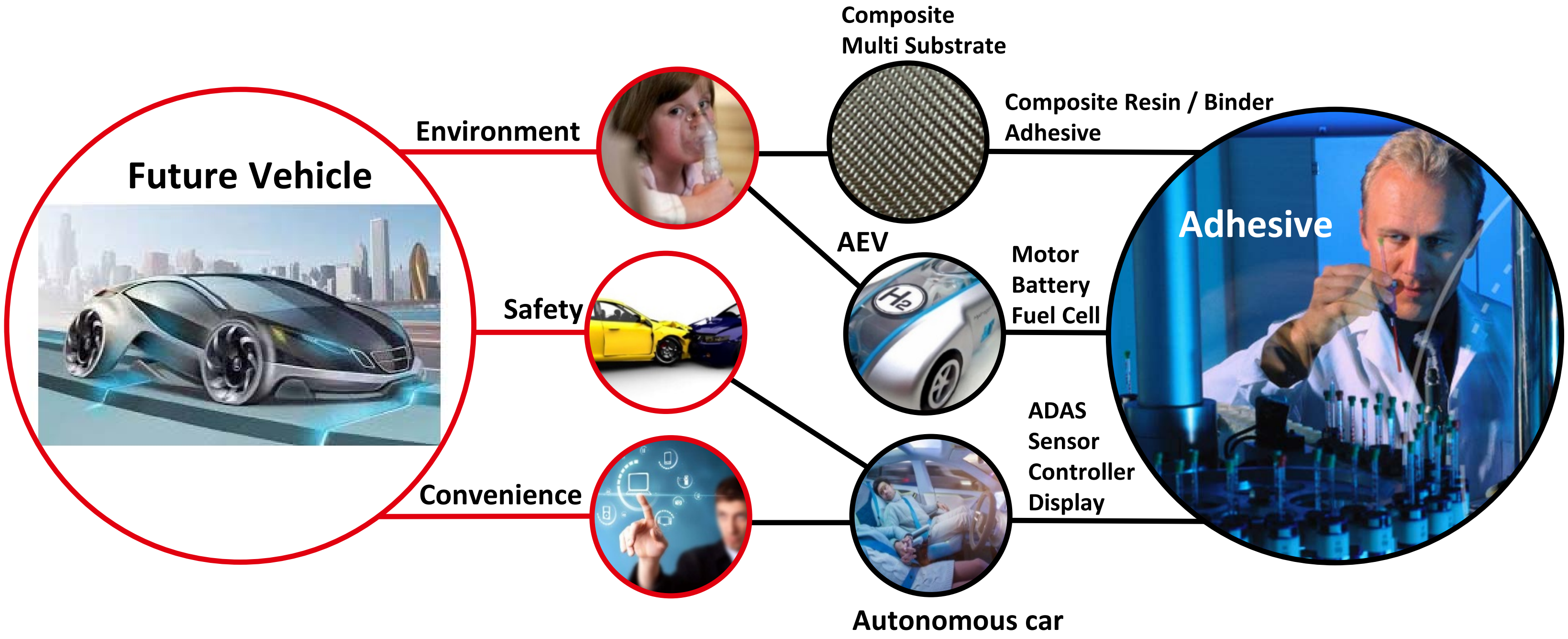
Agenda

1. Automotive Material Trends
2. Multi-substrate bonding
3. Design Considerations

Bridges - Future Vehicle & Adhesive



Automotive market drivers and characteristics
Why new substrates ?

Global Megatrends

- Population & GDP growth
- Sustainability
- Energy cost & fuel efficiency

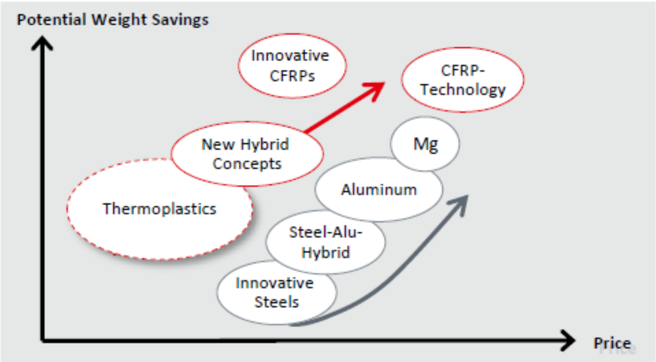
Industry Trends

- High demand for travel
- Lightweight, comfort, NVH
- Cost reduction

Outcome

- New designs
- New materials
- New processes
- Mass production

“The right material, at the right place”



New

“Lightweighting through integration of multi-materials”

〉 **The use of new metal substrates and composites is driven by market mega trends**

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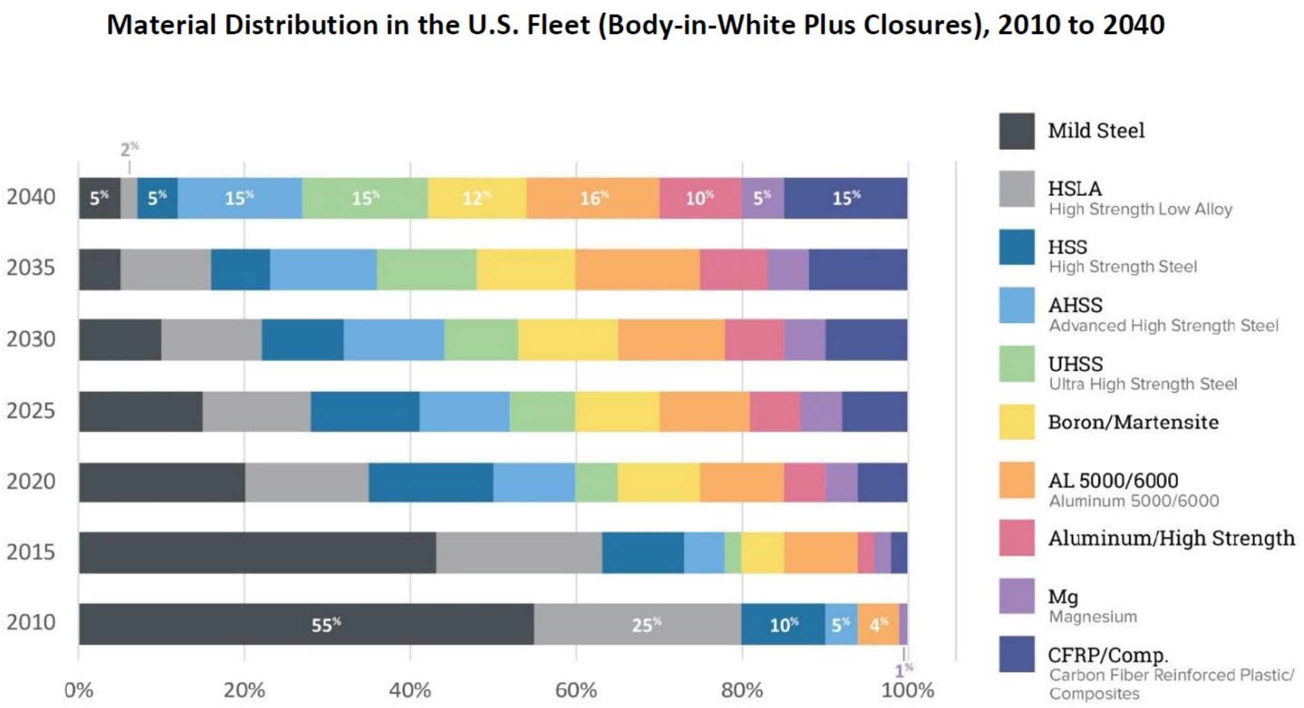
Materials in BIW: Usage Projection 2010 → 2040



Source: CAR Research

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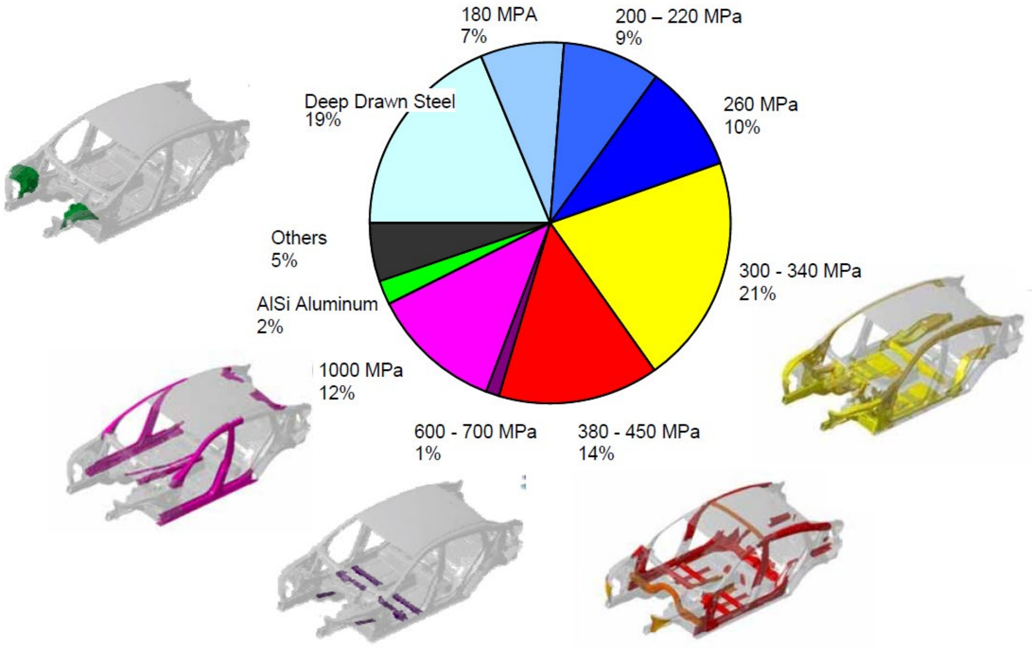
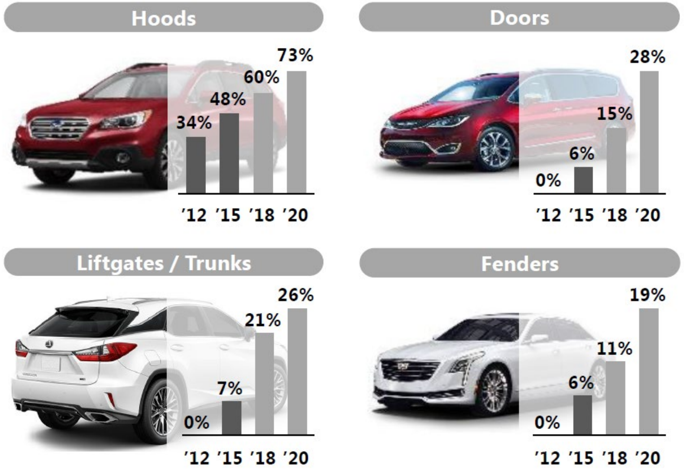
The right material, at the right place

Material distribution in BIW

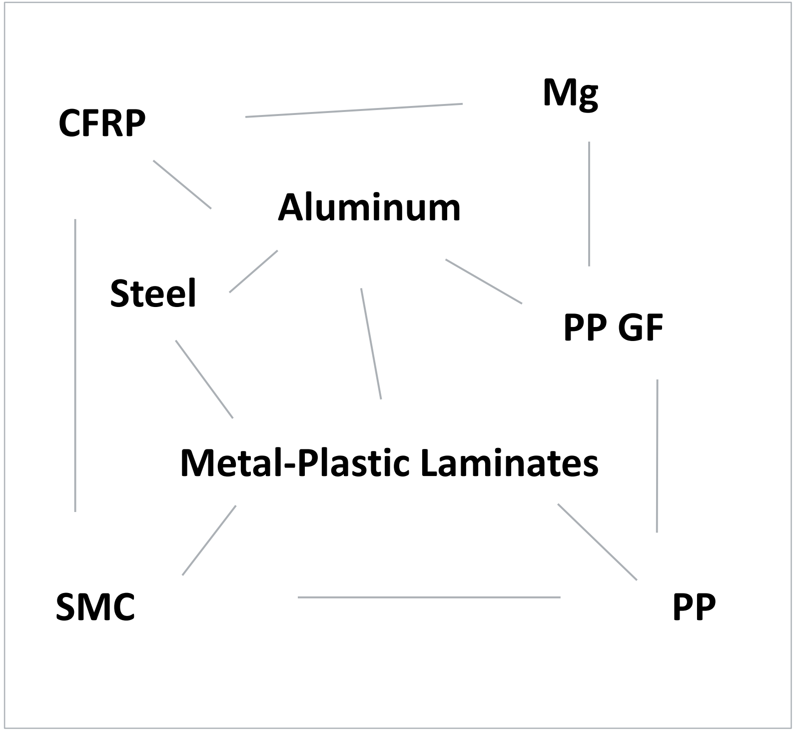


Aluminum penetration rates for closures

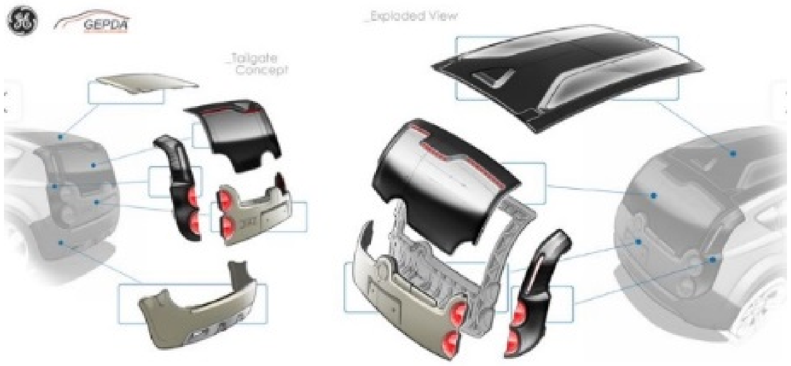


Lightweight Materials

Need for multi-material joining solutions



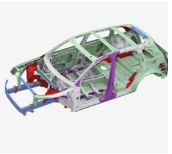
How to join?



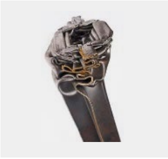
Automotive Assembly Process

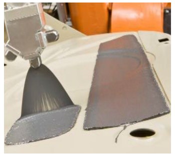
Demand for Integrated Design and Process Engineering

Design	Metal	Press Shop	Body Shop		Paint Shop			Lifecycle
Body Engineering	Coil	Cleaning & Stamping	Welding	Structural & Antiflutter Adhesives	Surface Treatment & E-Coat	Sealing / UBC & LASD	Paint System: Primer / BC / TC	Environment









Fundamental metal surface modification know how to facilitate forming, bonding & painting

Challenges in structural joining of lightweight designs
Mixed Material Body

Technical challenges

- Assembly Process Targets
  - Access to workpiece to form joint
  - Application speed to join materials (cycle time)
  - Ability to confirm joint formation / move workpiece after joining
- Logistics: Inventory/shelf-life, transport, application labor, equipment, waste
- Post joining processing
  - Impact to joint in remaining assembly/paint shop process
  - Paint-Shop oven temperature impact: CTE mismatch situations
- Joint performance targets (during and post-assembly)
  - Joining with/without surface preparation or insulating layer
  - Post-joint corrosion of mixed materials/galvanic cell formation
  - Crash load capability and Long term durability of joint

Need fundamental understanding of substrates, location, application, and materials

Multi-material joining technology

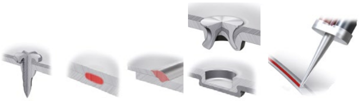
Multi-Material Joining Techniques

- **Chemical Adhesives**
  - Epoxies
  - Acrylics
  - Cyanoacrylates
  - Urethane
- **Welding/Brazing**
  - Friction Stir Welding
  - Explosion Welding
  - Laser Brazing
  - Magnetic Pulse Welding
- **Mechanical Joining**
  - Self Piercing Rivets
  - Self-Threading Screws

Source: Frost Sullivan - Innovations in Multi-material Joining

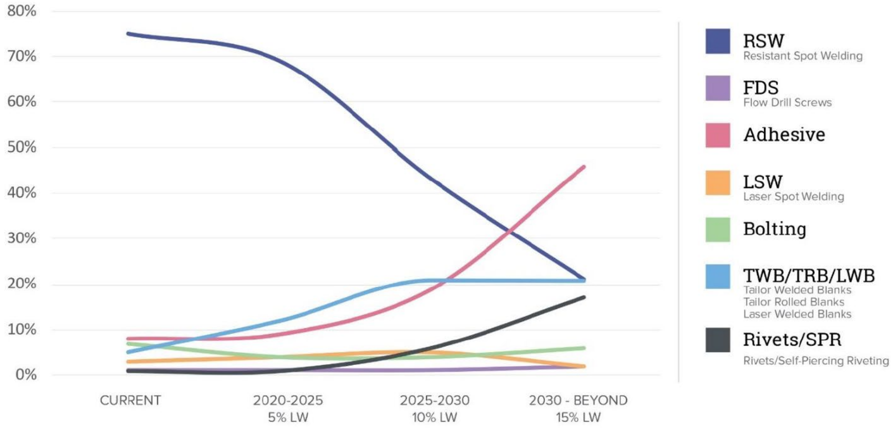
Comparison of Joining Technologies

key	
-	Demand can hardly be met
0	Demand can be met
+	Demand can easily be met



Demands	screwing (FDS)	welding	brazing	riveting / clinching	adhesive bonding
one-sided accessibility	0	0	0	-	0
base metal stability	-	+	-	-	-
tightness	0	+	+	-	+
various material pairing	+	0	0	0	+
bypassing of tolerances	+	-	-	0	-
low number of must-have manufacturing equipment	0	-	-	-	-

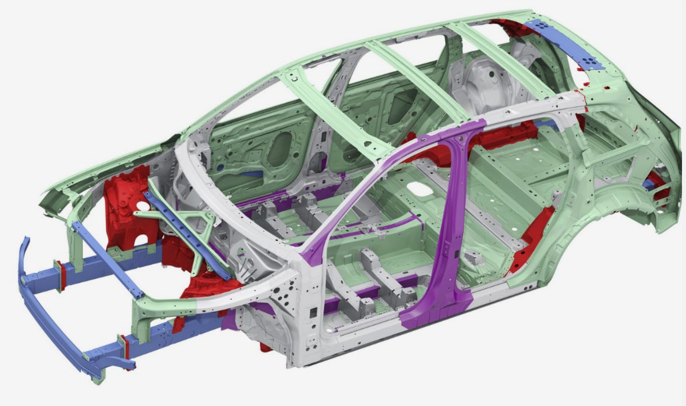
Source: AUDI



Note: LW= Lightweighting
Source: CAR Research, Lucintel

Automotive Structural Bonding Trends

Lightweight



Structural Bonding Trends

- **Increased use of lightweight materials**
- Consideration for long term strength, durability, and insulation of bond.
- Demand for initial mechanical performance & retention of workpiece position – assembly cycle time/through-put requirement
- Dependence upon location of workpiece in vehicle and within assembly process
- Balance of Materials, Equipment, Labor, & Maintenance with bonding operation

Need for lightweight drives increased use of adhesive joining technology

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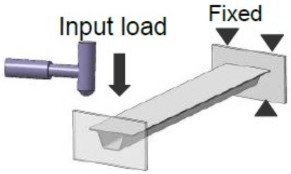
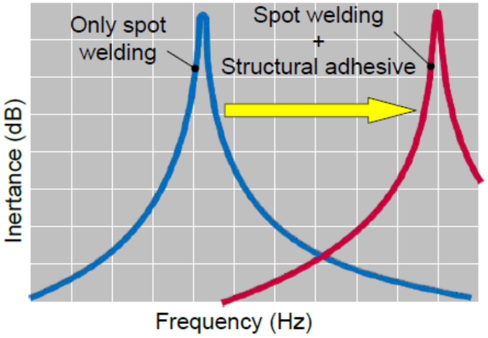
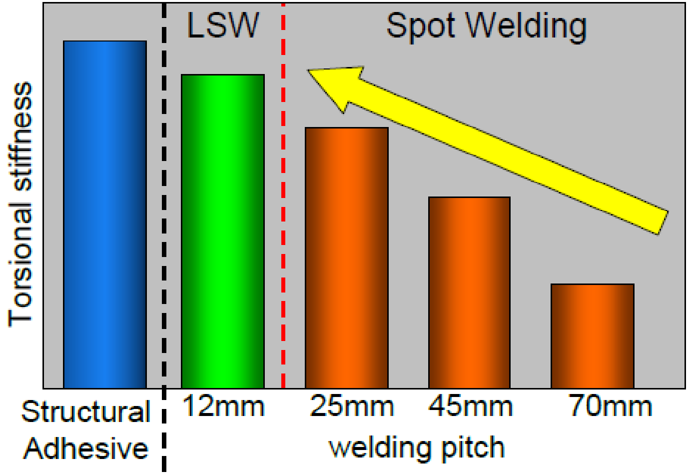
Comparison of Joining Methods
Dynamic & torsional stiffness

- Adhesives are applied continuous joint in specimen
- Vibrational stress associated with spot welds and mechanical fasteners can be reduced or eliminated by forming continuous bond

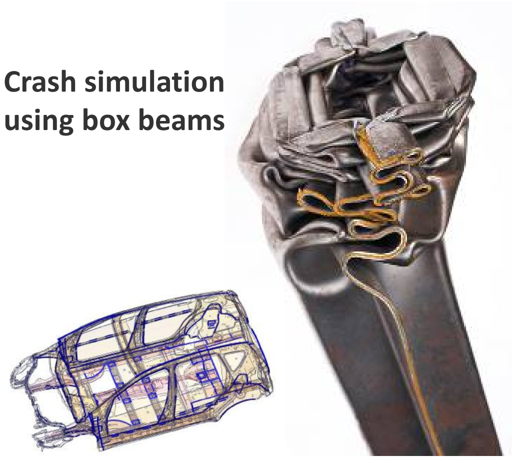


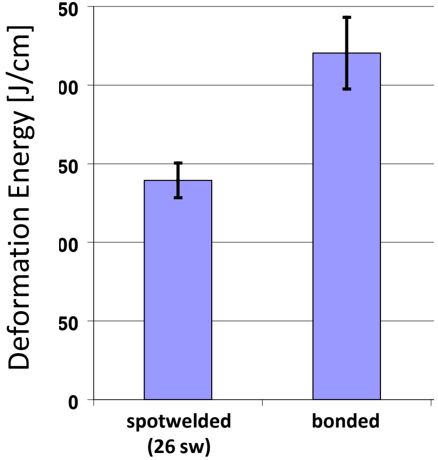


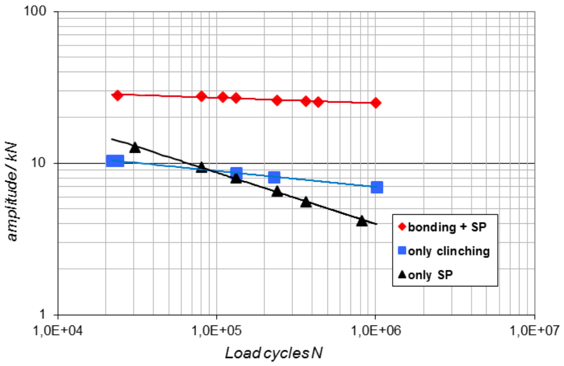
- Structural adhesive performed good torsional stiffness
- Compared with spot, laser screw welding



Comparison of Joining Methods







Accepted benefits of structural bonding

- Improved stiffness of car body assemblies
- Up to 25 % increase of energy absorption in the metal structures
- Increased fatigue durability

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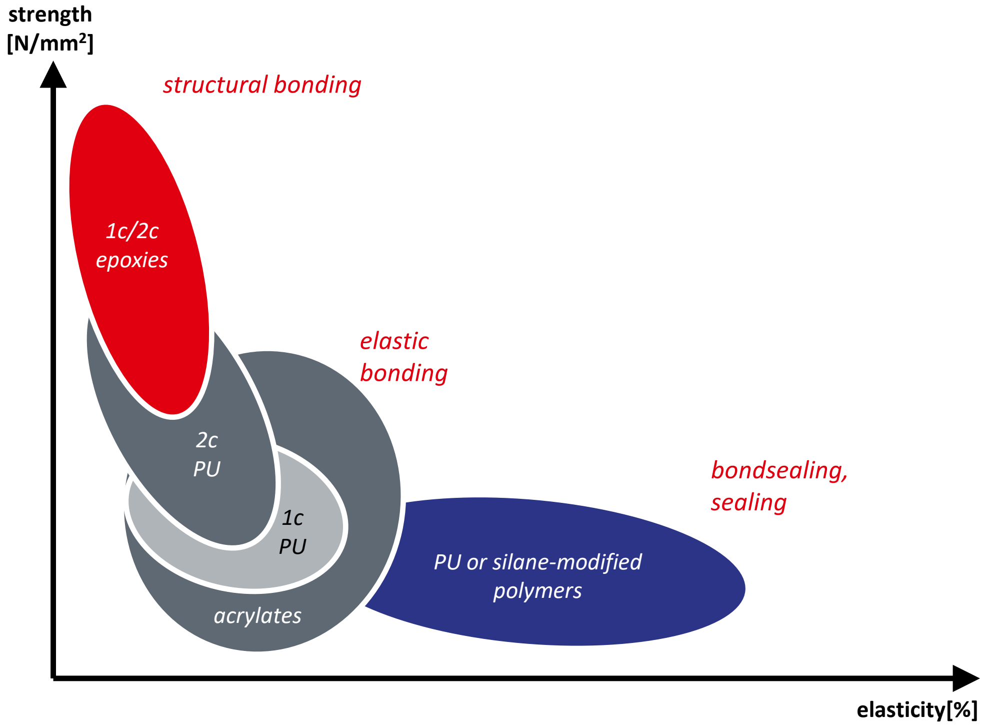
Multi-substrate Bonding

Adhesive technologies – mechanical property profile



- Composite bonding adhesives profile: Flexibilized structural and semi-structural adhesives
- Typical adhesive technologies: 1C/2C epoxies, 1C/2C PU, acrylates
- Typical sealant technologies: 2C PU, silane-modified polymers

Comparison of Adhesive Chemistries

Epoxies

- Epoxy adhesives are some of the most commonly used adhesives in most of the manufacturing industries.
- This is primarily because of the high strength bond formation post curing.
- The bonding between two surfaces may be fastened using heat or ultraviolet radiation.

Acrylics

- High bonding strength on plastic and metal
- However, they tend to have lower vibration/impact resistance than epoxies (thus, lower fatigue resistance) and lower performance at extreme temperature. As a result, it is not advisable to use them for transport vehicles.

Cyanoacrylates

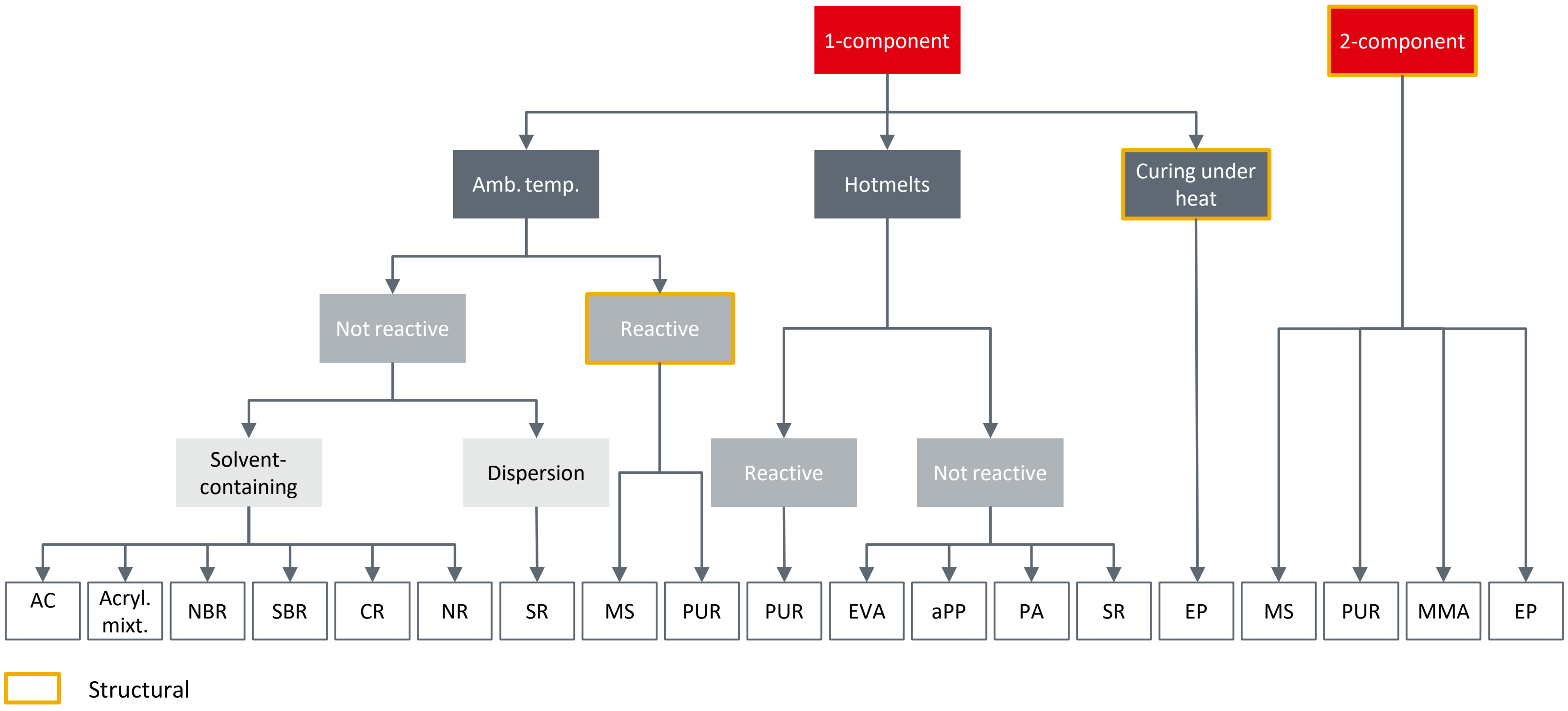
- Cyanoacrylates tend to provide decent shear strength for bonding of rubber and plastics (with the help of primers); but they are often rigid and show impact and peel resistance.

Urethane

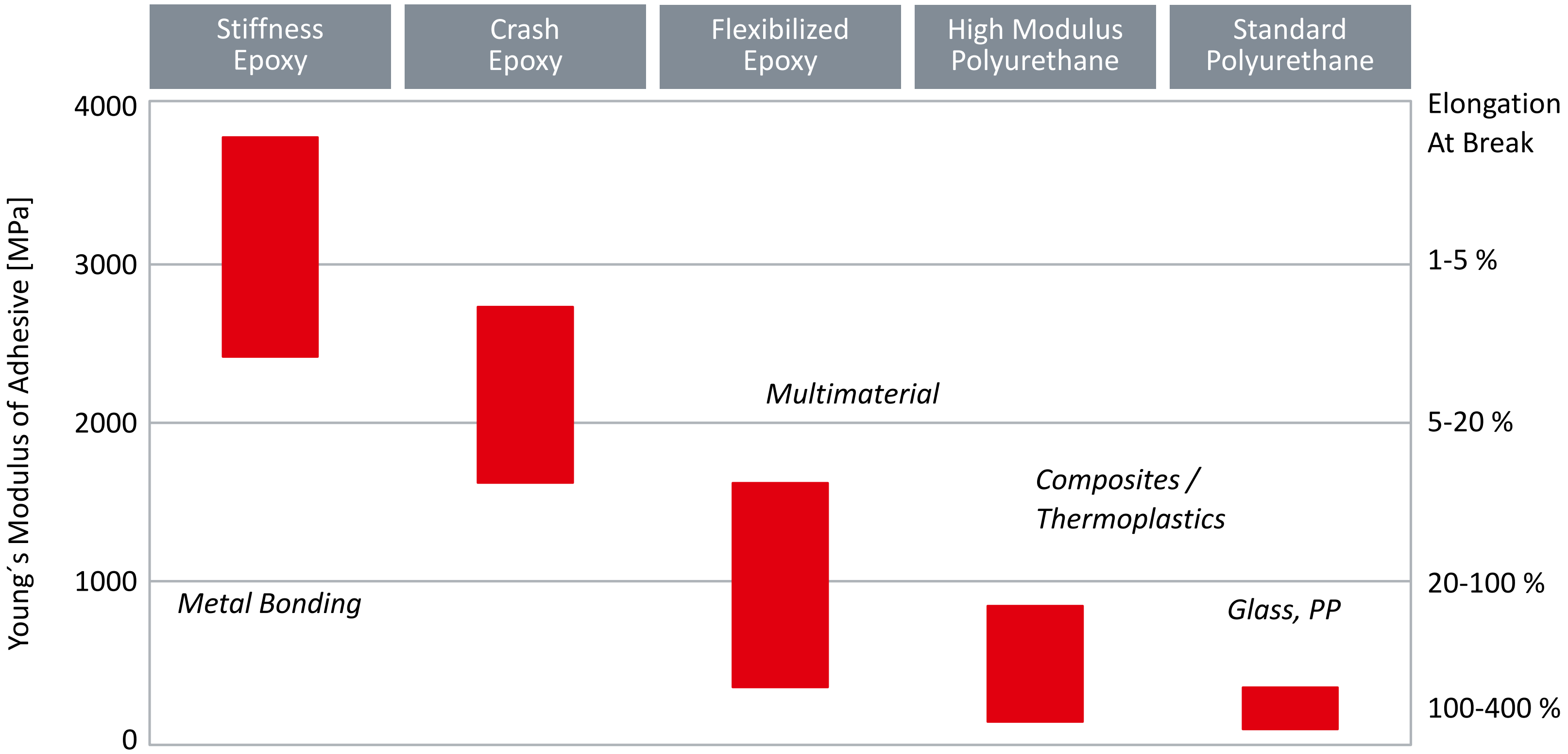
- Urethanes are quite flexible, but have lower strength in general.
- They can be relatively good binding agents for plastic and rubber
- Prices are lower compared to other adhesive types.

Source: Frost Sullivan - Innovations in Multi-material Joining

Comparision of Curing Mechanisms
Methods to Achieve



Adhesives Portfolio for Multimaterial Designs



Composite Bonding
General adhesive classification

Material Selection Driven by Desired Application Properties

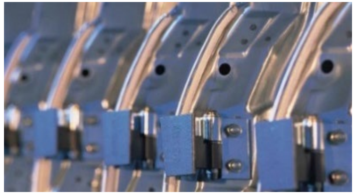
High modulus
High strength
Medium elongation

Low modulus
Low-medium strength
High elongation

	Structural bonding	Semi-structural Elastic bonding	Sealing / Elastic bonding
Application examples	**Body structure, structural components**	**Roof, Hood, Closures hang on panels**	**All flange joint sealing, hang-on parts Flaps, Spoiler**


Source: Audi A8


Source: BMW

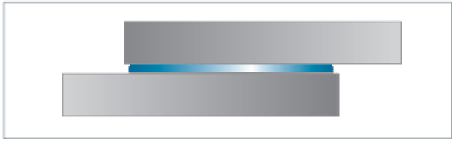


Adhesive Joint Design

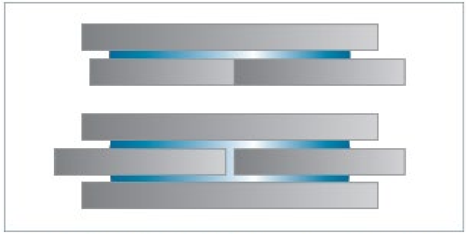
Types of Joints

Joint Geometry: Refers to general shape of an adhesive bond

BUTT JOINT: A butt joint is formed by bonding two objects end to end.

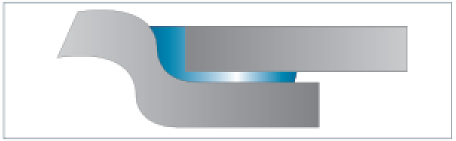


LAP/OVERLAP JOINT: A lap joint, also called an overlap joint, is formed by placing one substrate partially over another substrate.

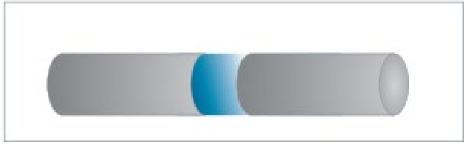


STRAP JOINT (SINGLE OR DOUBLE): A strap joint is a combination overlap joint with a butt joint.

SCARF JOINT: A scarf joint is an angular butt joint. Cutting the joint at an angle increases the surface area.



OFFSET JOINT: The offset joint is very similar to the lap joint.



CYLINDRICAL JOINT: A cylindrical joint uses a butt joint to join two cylindrical objects.

Adhesive Joint Design
Joint Stresses

JOINT STRESS DISTRIBUTION

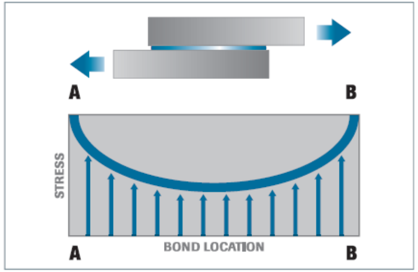
Joint stress distribution is the location of stresses within a bond.

Stress: Usually expressed as Newtons per square meter (N/M²), which is equivalent to a pascal (Pa). In the English system, stress is normally expressed in pounds per square inch (psi).

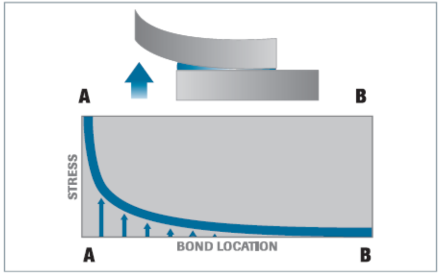
TYPES OF STRESSES

There are several types of stresses commonly found in adhesive bonds, including:

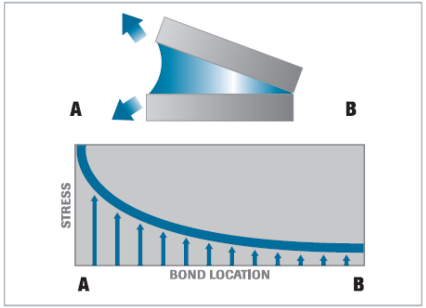
- Shear
- Peel
- Tensile
- Cleavage
- Compressive



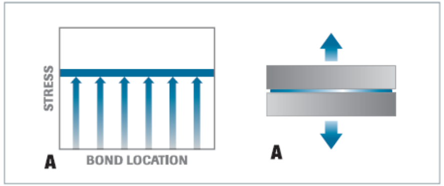
SHEAR STRESS: A shear stress results in two surfaces sliding over one another.



PEEL STRESS: A peel stress occurs when a flexible substrate is being lifted or peeled from the other substrate. **NOTE:** The stress is concentrated at one end.



CLEAVAGE STRESS: A cleavage stress occurs when rigid substrates are being opened at one end. **NOTE:** The stress is concentrated at one end.



TENSION STRESS DISTRIBUTION: When a bond experiences a tensile stress, the joint stress distribution is illustrated as a straight line. The stress is evenly distributed across the entire bond. Tensile stress also tends to elongate an object.

COMPRESSION STRESS DISTRIBUTION: When a bond experiences a compressive stress, the joint stress distribution is illustrated as a straight line. The stress is evenly distributed across the entire bond.

Adhesive Joint Design
Design Considerations

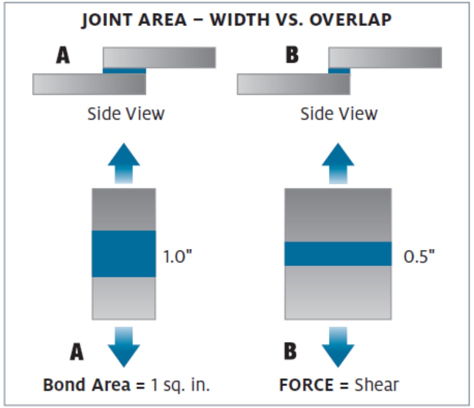
There are several design guidelines to be considered when designing an adhesive joint.

MAXIMIZE SHEAR/MINIMIZE PEEL AND CLEAVAGE

Note from the stress distribution curve for cleavage and peel that these bonds do not resist stress very well. The stress is located at one end of the bond line. Whereas, in the case of shear, both ends of the bond resist the stress.

MAXIMIZE COMPRESSION/MINIMIZE TENSILE

Note from the stress distribution curves for compression and tension that stress was uniformly distributed across the bond. In most adhesive films, the compressive strength is greater than the tensile strength. An adhesive joint that is feeling a compressive force is less likely to fail than a joint undergoing tension.



JOINT WIDTH VS. OVERLAP

Note from the shear stress distribution curve that the ends of the bond receive a greater amount of stress than does the middle of the bond. If the width of the bond is increased, stress will be reduced at each end and the overall result is a stronger€joint.

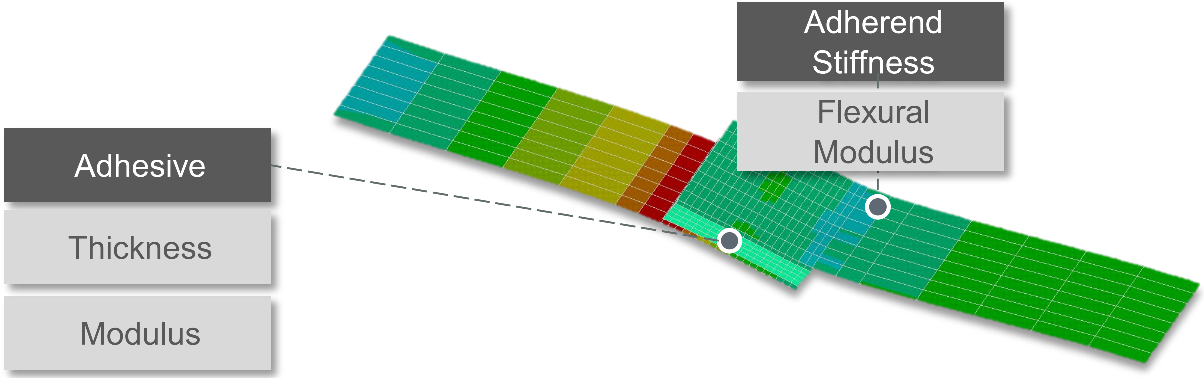
In this same overlap joint, if the overlapping length is greatly increased, there is little, if any, change in the bond strength. The contribution of the ends is not increased. The geometry of the ends has not changed, thus their contribution to the bond strength has not changed.

As a general rule, increase the joint width rather than the overlap area (“wider is€better”).

Adhesive Joint Design

Parameters Affecting Joint Performance

- Effective joint design can be driven by
  - adherend stiffness properties,
  - bond line thickness, and
  - the use of suitable adhesive grade



Understand impact by adherend stiffness (layup) and bondline thickness using analytical approaches (Hart-Smith, VDI2014), ESAComp (Mortensen 2001), and FEA

Adhesive Joint Design Parameters

Discussion

Stiffer substrate is expected to result in lower bondline stressing although bending moment acting to joint and substrates will increase

- Stress peak reduction predicted by ESAComp is less pronounced than predicted by the Hart-Smith analysis
- Conclusions confirmed by using thicker substrates but not yet using stiffer layup design

Reduction of stress peaks using thicker adhesive layer evident in shear but negligible in peel; thicker bondline results also to higher bending

- Effect of adhesive thickness predicted by analysis opposite to experimental work findings (da Silva et al. 2006, Harris and Fay 1992)

Use of lower modulus adhesive more effective way to reduce stresses than by realizing thicker bondline

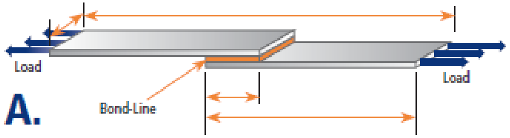
- Lower modulus may be associated to lower intrinsic strength properties
- How flexible may be an adhesive still meeting stiffness requirements of passenger car?

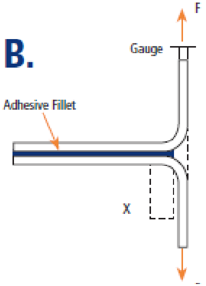
Adhesive Joint Design

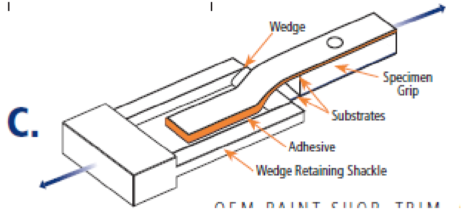
Common Automotive Adhesive and Sealant Standards

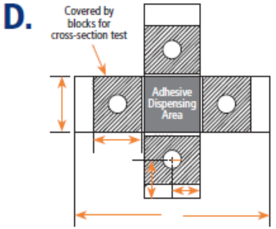
TEST NAME	STANDARDS	DESCRIPTION
Lap shear	ASTM D1002 (metals) ASTM D3163 (plastics) ASTM D5868 (FRP) DIN EN 1465	Determines the shear strength of adhesives when measured on a single lap shear specimen. Standard ASTM sample size is 1" x 4" with an overlap of ½" or 1". Tests often conducted as 23C, -40C, and 80C for transportation, and requirements are OEM specific. **SEE ILLUSTRATION A**
T-Peel	ASTM D1876 ISO 11339	Measures the strength of the adhesive bond in peel. Generally conducted on thin metals that can be bent. Tests may be conducted across a broad range of temperature and environmental conditions. Requirements are OEM specific. **SEE ILLUSTRATION B**
Impact Wedge Peel	ISO 11343	Measures the resistance to cleavage fracture of structural adhesives at a relatively high strain rate. Often conducted at 23C, -40C, and 80C. Results used as an indicator of toughness and crash resistance. **SEE ILLUSTRATION C**
Cross Tension (Cross Peel)	ASTM D897 SAE J 1553-1995	Determines the strength of an adhesive bond in tension. Often used for anti-flutter adhesives because the movement of outer panels away from supporting structures creates a tensile load. **SEE ILLUSTRATION D**
Expansion	SAE J 1918-2002	Method for determination of expansion and water absorption of automotive sealers.
VOC content	OEM specific	Measure VOCs released in plant or that would escape into cabin from cured adhesives.
Weldability	OEM specific	Includes a battery of tests with OEM specific criteria, such as flammability, weld squeeze force, and weld nugget formation.
Salt spray test	ASTM B117 DN50021 OEM specific	Salt spray corrosion condition used as a quick predictor of corrosion resistance. Some OEMs maintain their own standard.
Cyclic Corrosion Test	SAE J2334 VDA 621-415 OEM specific	Cycle of salt spray, temperature, and humidity conditions that is used to simulate long-term environmental exposure in field conditions. Some OEMs maintain their own standard.

Source: Adhesive and Sealant Council, OEM Paint Shop Adhesive & Sealant Selection Guide, 2018









Summary

- Automotive Design trends indicate more demand for lightweight and multi-material construction.
- There are challenging and complex assembly process guidelines that impact the selection of a structural joining technology
- Chemical Adhesives provides application consistency and performance advantages when used for automotive joining:
  - More uniform stress distribution
  - Uniformity of surface and texture of the joined materials
  - Improved stiffness and fatigue durability of car body assemblies
  - Sealed joints: Adhesives also act as sealants
    - preventing loss of pressure or liquids
    - blocking the penetration of condensation/water/air
    - insulating against corrosion.
  - Adhesives also act as an electrical and thermal insulator.
- There are effective engineering-material-application guidelines to be considered when designing an adhesive joint.

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Thank you!